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p. 384

WHITE SHARK *CARCHARODON CARCHARIAS* FROM THE GULF OF CALIFORNIA WITH A LIST OF SHARKS SEEN IN MAZATLAN, MEXICO, 1964.—Although there have been numerous reports of the white shark from the eastern Pacific Ocean, there has been no definite record of this species between California and Panama (Bigelow and Schroeder 1948, Fishes of the western North Atlantic. Sharks. Sears Found. Mar. Research Mem. (1) :144–145). On 25 January 1964, I saw a juvenile male specimen of *Carcharodon carcharias* (Linnaeus) at Playa Sur in Mazatlan, Mexico. The following is a partial description with body measurements in centimeters made normal to the long axis of the specimen: total length 196; tip of snout to base of caudal 154, to fork 171, to first dorsal fin 59, to second dorsal fin 130; upper teeth broadly triangular, strongly serrated, total 24, no symphysials, second tooth from the center 1.2 cm at the base, 1.5 cm high; lower teeth narrower, with a broad base and narrow cusp, strongly serrated, total 22, no symphysials, second tooth from the center 1.1 cm at the base, 1.7 cm high; claspers 10.5 cm to pelvic axil.

The shark was taken by a small shark-fishing boat operating northward out of Mazatlan. It is sufficiently well known to the local fishermen to have the common name "tornina." Although the water temperature was not observed at the time, the January mean for waters near Mazatlan is about 72 F. (Surface water temperature and salinity. Pacific coast. North and South America and Pacific Ocean Islands. 1962. C. and G. S. publication 31-3:64, 1st ed.).

In addition to *Carcharodon*, I have seen 18 other species of sharks in Mazatlan, which is the largest shark fishing center in the eastern Pacific Ocean. The sharks are used for their flesh (salted or fresh), and some for their hides and fins as well. The following species of sharks were observed in the Mazatlan shark fishery: *Carcharhinus altimus* (Springer); *C. azureus* (Gilbert and Starks); *C. galapagensis* (Snodgrass and Heller); *C. limbatus* (Müller and Henle); *C. porosus* (Ranzani); *C. velox* Gilbert; *Ginglymostoma cirratum* (Bonaterre); *Galeocerdo cuvier* (Peron and LeSueur); *Mustelus californicus* Gill; *M. lunulatus* Jordan and Gilbert; *Negaprion fronto* (Jordan and Gilbert); *Rhizoprionodon longurio* (Jordan and Gilbert); *Sphyrna lewini* (Cuvier, Griffith, and Smith); *S. media* Springer; *S. mokarran* (Rüppell); *S. tiburo* (Linnaeus); *S. zygaena* (Linnaeus); and *Triakis semifasciata* Girard.

Because of difficulties in nomenclature, it was deemed advisable to list the reference sources used in identifying the sharks. The titles and page references are given below, with the species of sharks, in parentheses, following the source. 1. Beebe and Tee-Van 1941, Zoologica 26 (2) :96 (*G. cirratum*); 2. Bigelow and Schroeder 1948, Fishes of the western north Atlantic. Part 1. Lancelets, cyclostomes and sharks. Sears Found. Mar. Res. Mem. (1) :134, 420 (*C. carcharias, S. tiburo*); 3. Beebe and Tee-Van 1941:105, and Bigelow and Schroeder 1948:309 (*N. fronto*); 4. Garrick and Schultz 1963, in Sharks and Survival, P. W. Gilbert, ed., pp. 3–60 (*G. cuvier, S. lewini, S. mokarran, S. zygaena*); 5. Beebe and Tee-Van 1941:112, and Garrick and Schultz 1963:10 (*R. longurio*); 6. Roedel and Ripley 1950, Calif. Div. Fish Game Fish Bull. No. 75:51 (*T. semifasciata*); 7. Springer 1939, Proc. U. S. Natl. Mus. 86 (3058):467–468 (*M. californicus, M. lunulatus*); 8. Springer 1940, Stanford Icthyol. Bull. 1 (5):164 (*S. media*); 9. Rosenblatt and Baldwin 1958, Calif. Fish Game 44 (2):137–159, and Garrick, personal communication (species of *Carcharhinus*).—SUSUMU KATO, *U. S. Bureau of Commercial Fisheries Biological Laboratory, San Diego, California.*

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The Copepod Ectoparasite *Sphyrion lumpi* (Kroyer) in relation to Redfish *Sebastes marinus* (L.) in the Gulf of Maine.

BY GEORGE F. KELLY AND ALLAN M. BARKER

Reprinted from
International Commission for the Northwest Atlantic Fisheries
Special Publication Number 6, 1965.

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THE COPEPOD ECTOPARASITE *SPHYRION LUMPI* (KROYER) IN RELATION TO REDFISH *SEBASTES MARINUS* (L.) IN THE GULF OF MAINE

By

George F. Kelly and Allan M. Barker[1]

ABSTRACT

Redfish is the primary host of *Sphyrion lumpi*, a copepod ectoparasite, in much of the western part of the Gulf of Maine. Sample data from commercial landings during 1942-62 were analyzed for seasonal and annual variations in parasite incidence, depth distribution, sex composition and size composition of parasitized redfish. Parasite incidence increased more than two-fold between 1943-47 and 1957-62. Many aspects of the host-parasite relationship support a hypothesis that small redfish mortality may be caused by *Sphyrion* infestation.

INTRODUCTION

The parasitic copepod *Sphyrion lumpi* is found abundantly on redfish in a large portion of the Gulf of Maine. Since 1942, redfish landings have been sampled routinely at New England fishing ports, the samples including notation of the presence of *Sphyrion*, and degree of infestation of the host. In this paper, we summarize these data to show the relation of the parasite to Gulf of Maine redfish as indicated by *Sphyrion* incidence with respect to sex and size of its host. We examine effects of this parasite on the host, and suggest some factors that may limit the range of *Sphyrion* in this area.

OCCURRENCE OF *Sphyrion*

Kroyer (1845) first described this parasite and named it *Lestes lumpi* from a specimen attached to a lumpfish, *Cyclopterus lumpus*, collected near Iceland. When Wilson (1919) established the new copepod family Sphyriidae, the name of the parasite already had been changed several times, and it had been found to infest several species of fish. In their report of the incidence and distribution of *Sphyrion* on redfish in the Newfoundland area, Templeman and Squires (1960) reviewed taxonomic changes and the many host records for the whole North Atlantic. It is sufficient to cite this reference at the present time and confine our comments to records from the Gulf of Maine.

Wilson (1919) was the first to associate *Sphyrion* with redfish in the Gulf of Maine region, but he did not suggest that redfish was the principal host. The start of the Gulf of Maine redfish fishery in 1935 revealed a high incidence of *Sphyrion* on redfish and, simultaneously, made this parasite economically important when embedded remains of the female parasite's head reduced the value of redfish fillets.

Herrington, Bearse, and Firth (1940) reported on abundance and distribution of *Sphyrion*, and the frequency of occurrence of its embedded remains in redfish fillets from the Gulf of Maine. Nigrelli and Firth (1939) reviewed the taxonomy of *Sphyrion* and corroborated Wilson's earlier classification. They noted that the parasite was found principally on larger redfish, and that distribution of the *Sphyrion* population in this region was confined to the western portion of the Gulf of Maine, with no *Sphyrion* on redfish from western Nova Scotia near Browns Bank. Perlmutter (1951) noted that approximately 92% of the parasites were attached between the base of the dorsal fin and lateral line of Gulf of Maine redfish. He concluded that this pattern of attachment was caused primarily by the fish's ability to scrape off parasites from all but that region of the body.

The frequency of occurrence of *Sphyrion* was used by Sindermann (1961) in studies of several parasites considered as possible parasitological tags for redfish stock identification in the western North Atlantic. Most recently, Williams (1963) reported the incidence of *Sphyrion* on redfish

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to be less than 3% at several locations in the eastern North Atlantic, based on examination of a limited number of *marinus*-type and *mentella*-type *Sebastes* specimens sampled from commercial landings at a fish market in Hull, England, over a 13-month period.

METHODS

All material used in this study was obtained from iced redfish catches on commercial otter trawlers. Samples consisted of 100, occasionally 200, fish. Data recorded include date of sample, location and depth of fishing, sex and length of host fish, number of copepod parasites and stage of parasite infestation. Three stages of infestation were defined:(first) live copepod - live animal still attached to the fish, (second) sore-copepod torn loose, leaving the embedded head and an open wound, and (third) spot - scarred remnant of a healed sore appearing externally as a swollen lump, and internally as an encysted hard tumor in the flesh. Observations of live copepods were confined to those visible to the unaided eye, and, therefore, the data are restricted to fully transformed females.

Since sampling was on commercial trips, samples were concentrated in areas of heavy fishing effort and were not uniformly distributed over the fishing grounds. Table 1 summarizes the number of redfish samples found to contain *Sphyrion* infestation from each statistical subarea in the Gulf of Maine, by year, from 1943-1962 (Fig. 1). It should be understood that sampling was not confined

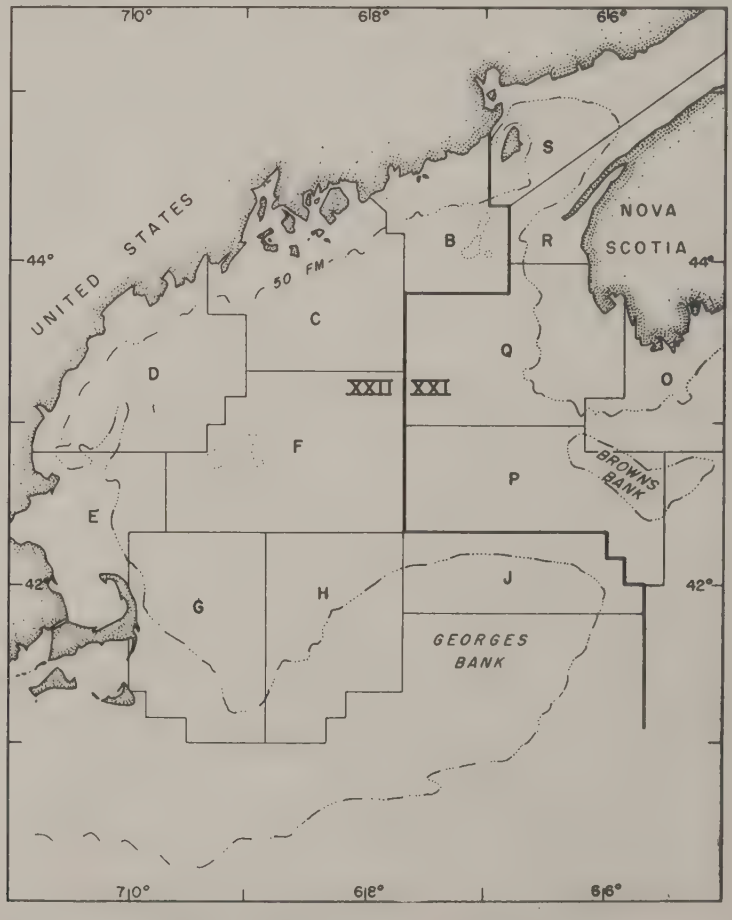

Fig. 1. Statistical subareas of the Gulf of Maine.

TABLE 1. NUMBER OF SAMPLES OF PARASITIZED REDFISH TAKEN IN THE GULF OF MAINE BY STATISTICAL SUBAREA 1943-62

Subarea	'43	'44	'45	'46	'47	'48	'49	'50	'51	'52	'53	'54	'55	'56	'57	'58	'59	'60	'61	'62
XXII B									-	1	2	1	6	26	38	43	20	10	3	5
	36	26	22	8	4	-	1	2												
C									-	1	-	-	14	30	52	33	21	6	7	7
D	28	10	7	9	-	-	-	-	2	1	1	1	8	21	23	29	12	6	22	11
E	18	17	16	15	6	-	3	-	-	-	-	1	-	6	10	-	6	6	3	12
F	30	30	32	21	26	12	3	8	19	18	12	12	14	54	80	53	33	23	36	24
G									16	3	4	1	4	4	8	4	14	3	8	7
	22	23	25	13	16	6	7	-												
H									1	5	1	1	2	8	4	5	1	2	4	2
XXI P, Q, R, S	-	3	12	11	2	-	-	-	-	2	-	-	-	8	9	2	5	17	18	5
Mixed areas	-	-	-	-	-	-	-	-	7	2	1	3	3	12	-	6	10			3
Total	134	109	114	77	54	18	14	10	45	33	21	20	51	169	224	175	122	73	101	76

to these areas; many thousands of fish were examined from other parts of the Gulf of Maine and eastward, but *Sphyrion* was found on redfish only in these subareas in the vicinity of the Gulf of Maine.

The greatest number of samples was obtained from the area of infestation during 1943-47 and 1955-62. The small number of samples collected from 1948 through 1954 was the result of a general movement of the U.S. redfish fleet from the Gulf of Maine eastward to fishing grounds off Nova Scotia, on the Grand Banks, and in the Gulf of St. Lawrence.

We are indebted to Messrs. C.F. Bocken, P.H. Chase Jr., G.M. Clarke, and R.S. Wolf for their assistance in collecting and analyzing data used in this study.

RESULTS

1. Range, Distribution, and Incidence of the Parasite.

Percentage incidence of live copepods in redfish samples is plotted for 1943-47 and 1957-62, and contour lines are drawn for 5% intervals (Fig. 2 and 3). General distribution of parasitized fish is similar for the 2 periods, and one is impressed with the strictly defined range of this *Sphyrion* population. All records of the parasite are from an area west of a line running from the northern edge of Georges Bank northeast to St. Mary's Bay on the western end of Nova Scotia. Within this area, most of the parasitized redfish are in depths between 90 and 220 m.

The area of occurrence of the parasite appears to be bisected by a region of low infestation extending NW-SE through Cashes Ledge near the center of the Gulf of Maine. *Sphyrion* incidence is higher north and south of this line. Within these smaller regions there are several localities of very high parasite incidence that persist from year to year (Fig. 2 and 3). During 1943-47, the 2 areas of highest infestation were off Cape Cod and near Mt. Desert Island. In 1957-62, these areas of high incidence remained, but there were 4 additional high infestation areas established where only lesser concentrations had existed in the earlier period. Incidence values higher than 15% were confined to comparatively small areas during 1943-47, while those regions during 1957-62 were much more extensive. The increase in size of areas of high parasite incidence indicates that *Sphyrion* has become more abundant in recent years. Despite these considerable changes in percentage incidence of the copepod on redfish, peripheral limits of the group of parasitized redfish have remained virtually unchanged.

2. Stages of Infestation.

The 3 stages of parasite infestation on redfish are similarly distributed in the Gulf of Maine (Fig. 2, 4, and 5). In 1943-47, the second and third stages (sores and spots respectively) were most plentiful off Cape Cod and near Mt. Desert Island, regions of highest copepod incidence. There was an additional concentration of third stage infestation near the tip of Jeffreys Ledge

south of Portland, Maine. Second and third stages were less numerous than the first, with the second stage least abundant.

Relative incidence of the 3 stages of infestation is illustrated more clearly with data from smaller areas within the Gulf, in which male and female redfish are treated separately (Fig. 6). In each statistical subarea, percentage of parasite incidence is approximately the same on males and females, and the sore stage is least numerous, usually less than 15% of the infected sample. In all except one subarea, the live copepod stage is the most numerous, usually comprising 45 to 58% of an infected sample. Subarea XXII D is the exception, where third stage infestation (spots) is much higher than the live copepod stage. This was noted above in Fig. 5 as a concentration of third stage infestation near Jeffreys Ledge.

3.

Annual Variation in Parasite Incidence.

Annual changes in percentage incidence of live copepods and total infestation (3 stages) for the entire Gulf of Maine area of parasite occurrence are shown in Fig. 7. The 2 curves are similar and, despite some marked fluctuations, each shows a significant trend toward higher incidence in recent years. Average incidence of live copepods rose from 5.8% in 1943-47 to 14.2% during 1957-62. These measures of incidence are comparable and are representative of the whole parasite population since sampling during both periods contained substantial collections from each

Fig. 2. Distribution of redfish with first stage infestation of *Sphyrion lumpi* in the Gulf of Maine, 1943-47.

Fig. 3. Distribution of redfish with first stage infestation of *Sphyrion lumpi* in the Gulf of Maine, 1957-62.

subarea. It should be noted that sampling during 1948 through 1954 was relatively light and these samples may not represent average conditions for the whole population. Annual incidence variations are seen in more detail in data for live copepods from a portion of the Gulf of Maine with male and female redfish separated (Fig. 8). Here again a more than two-fold increase in *Sphyrion* incidence is shown. Also, there has been an interesting change in relative levels of incidence on male and female fish; values for females were consistently higher than for males in 1943-47, but lower than male values during most of 1957-62. The significance of this reversal will be discussed later.

4. Seasonal variation in Parasite Incidence.

Incidence of live *Sphyrion* on redfish was highest in winter and spring and lowest during summer and fall (Fig. 9 and Tables 2 and 3). Data for the southern Gulf of Maine during 1943-47 show the highest value in February, a rapid decline until June, and generally low values from June through November. Parasitization of males and females followed a similar pattern, females showing consistently higher levels of incidence than males throughout most of the year.

In 1957-62, a similar winter-summer difference existed, but the magnitude of change was less than during the earlier period. There was a higher level of incidence at all seasons which reflects the recent general increase in parasite incidence mentioned earlier. Furthermore, the relative

Fig. 4. Distribution of redfish with second stage infestation of *Sphyrion lumpi* in the Gulf of Maine, 1943-47.

level of parasite incidence on males and females had changed from that of the earlier period, a reversal of values similar to that noted earlier in the year-to-year comparison.

The winter-summer cycle of variation suggests that the parasite infests the host in late winter and the number of parasitized fish decreases during the summer and fall, when the reproductive cycle is again repeated. The decrease may be caused by fish shedding the copepods, or it may be due to mortality of the parasitized fish.

5. Changes in Sex Ratio of Redfish.

The sex composition of Gulf of Maine redfish has changed considerably since 1942 when sexed samples of redfish were first collected (Fig. 10). From 1942 until 1954 the samples contained more than 54% females each year, the average being 55.6%. From 1955 through 1962 the proportion of females was below 53.5% each year, and the average decreased to 51.9%. The downward trend, which could be said to have started as early as 1949, has been most evident since 1955. It was accentuated during the last 4 years by the lowest percentages of female redfish observed since sex composition data were first collected routinely in 1942.

The sex composition of parasitized redfish (live copepod stage) has shown even greater change

TABLE 2. SEASONAL VARIATION IN NUMBER AND PERCENTAGE INCIDENCE OF LIVE *Sphyrion* ON REDFISH IN SOUTHERN GULF OF MAINE, SUBAREAS XXII, E, F, AND G, 1943-47. MALES AND FEMALES SEPARATED.

Month	1943		1944		1945		1946		1947		TOTAL		
	No. fish sampled	No. fish parasit.	No. fish sampled	No. fish parasit.	No. fish sampled	No. fish parasit.	No. fish sampled	No. fish parasit.	No. fish sampled	No. fish parasit.	No. fish sampled	No. fish parasit.	Percent parasitized
MALES													
Jan.	219	22	152	8	159	26	-	-	-	-	530	56	10.6
Feb.	144	9	76	14	39	12	51	2	-	-	310	37	11.9
Mar.	243	27	-	-	295	8	-	-	90	7	628	42	6.7
Apr.	130	7	258	19	73	0	49	2	91	2	601	30	5.0
May	179	13	313	9	693	32	453	31	283	24	1,921	109	5.7
June	281	5	433	10	314	5	159	2	241	9	1,428	31	2.2
July	196	2	583	8	265	4	409	12	360	7	1,813	33	1.8
Aug.	916	7	370	3	422	8	166	18	286	11	2,160	47	2.2
Sept.	136	1	331	1	453	3	232	10	394	2	1,546	17	1.1
Oct.	201	0	356	7	64	3	305	4	230	5	1,156	19	1.6
Nov.	304	9	382	8	138	1	54	0	48	5	926	23	2.5
Dec.	72	0	108	12	-	-	-	-	41	7	221	19	8.6
Total	3,021	102	3,362	99	2,915	102	1,878	81	2,064	79	13,240	463	-
Percent incidence		3.38		2.94		3.50		4.31		3.83		-	3.50
FEMALES													
Jan.	231	15	148	4	141	28	-	-	-	-	520	47	9.0
Feb.	156	16	124	29	61	16	49	4	-	-	390	65	16.7
Mar.	257	41	-	-	255	12	-	-	110	7	622	60	9.6
Apr.	145	3	342	22	127	0	51	2	109	9	774	36	4.7
May	221	17	287	10	807	52	490	78	317	37	2,122	194	9.1
June	369	20	567	22	386	9	241	6	459	16	2,022	73	3.6
July	304	5	817	12	335	6	491	31	440	10	2,387	64	2.7
Aug.	759	8	430	11	678	30	234	30	314	7	2,415	86	3.6
Sept.	189	0	419	4	447	14	368	38	406	12	1,829	68	3.7
Oct.	248	3	444	25	136	10	395	9	370	6	1,593	53	3.3
Nov.	296	1	468	10	162	3	46	1	52	0	1,024	15	1.5
Dec.	98	1	92	16	-	-	-	-	59	8	249	25	10.0
Total	3,273	130	4,138	165	3,535	180	2,365	199	2,636	112	15,947	786	-
Percent incidence		3.97		3.99		5.09		8.41		4.25		-	4.93

TABLE 3. SEASONAL VARIATION IN NUMBER AND PERCENTAGE INCIDENCE OF LIVE *Sphyrion* ON REDFISH IN SOUTHERN GULF OF MAINE, SUBAREAS XXII E, F, AND G, 1957-1962. MALES AND FEMALES SEPARATED.

Month	1957		1958		1959		1960		1961		1962		TOTAL		
	No. fish sampled	No. fish parasit.	No. fish sampled	No. fish parasit.	No. fish sampled	No. fish parasit.	No. fish sampled	No. fish parasit.	No. fish sampled	No. fish parasit.	No. fish sampled	No. fish parasit.	No. fish sampled	No. fish parasit.	Percent parasitized
MALES															
Jan.	148	7	275	39	294	20	158	26	–	–	296	37	1,171	129	11.0
Feb.	874	59	326	78	153	7	102	9	364	122	53	–	1,872	275	14.7
Mar.	800	140	334	57	321	59	326	77	313	70	188	53	2,282	456	20.0
Apr.	588	77	369	48	459	74	150	18	–	–	115	6	1,681	223	13.3
May	466	84	246	60	149	25	212	44	700	152	416	28	2,189	393	18.0
June	315	26	239	7	295	27	–	–	468	97	456	79	1,773	236	13.3
July	326	5	213	18	165	13	117	8	142	24	149	15	1,112	83	7.5
Aug.	251	11	169	7	248	18	241	27	199	18	422	11	1,530	152	9.9
Sept.	277	11	243	36	350	58	–	–	54	19	34	–	958	124	12.9
Oct.	281	21	83	7	–	–	191	13	–	–	–	–	555	41	7.4
Nov.	214	14	128	12	59	12	92	2	–	–	–	–	493	40	8.1
Dec.	90	6	–	–	99	15	–	–	170	28	–	–	359	49	13.6
Total	4,630	461	2,625	369	2,592	328	1,589	224	2,410	530	2,129	289	15,975	2,201	–
Percent incidence		9.96		14.1		12.7		14.1		22.0		13.6		–	13.8
FEMALES															
Jan.	152	4	325	51	206	11	142	19	–	–	304	40	1,129	125	11.1
Feb.	826	54	374	82	147	2	98	7	336	106	47	–	1,828	251	13.7
Mar.	700	106	366	53	381	57	274	48	287	55	210	54	2,218	373	16.8
Apr.	712	114	331	41	441	59	150	10	–	–	85	5	1,719	229	13.3
May	534	87	354	74	151	23	188	29	600	160	384	46	2,211	419	19.0
June	435	56	261	5	305	34	–	–	532	102	465	63	1,998	260	13.0
July	374	12	287	18	135	10	183	9	158	21	151	14	1,288	84	6.5
Aug.	349	15	231	8	252	23	259	25	201	25	478	71	1,770	167	9.4
Sept.	323	7	257	31	550	95	–	–	46	22	66	–	1,242	155	12.5
Oct.	319	41	117	6	–	–	209	29	–	–	–	–	645	76	11.8
Nov.	286	22	172	19	41	2	108	7	–	–	–	–	607	50	8.2
Dec.	110	10	–	–	101	9	–	–	130	20	–	–	341	39	11.4
Total	5,120	528	3,075	388	2,710	325	1,611	183	2,290	511	2,190	293	16,996	2,228	–
Percent incidence		10.3		12.6		12.0		11.4		22.3		13.4		–	13.1

Fig. 5. Distribution of redfish with third stage infestation of *Sphyrion lumpi* in the Gulf of Maine, 1943-47.

than the total Gulf redfish population. From 1943 through 1951 the proportion of females in the samples was greater than 55% each year. From 1952 through 1962 females comprised less than 54% in all except one year, and during 4 successive years the value was as low as 46-49%.

Comparing the 2 curves in Fig. 10, it is evident that sex ratios of both parasitized and non-parasitized redfish changed during the period of study, the change being greater in the parasitized portion of the population than in the whole Gulf of Maine redfish population. This general alteration in sex ratio will be discussed later in relation to the reversal in percentage incidence of *Sphyrion* on male and female redfish that was noted earlier.

6. Depth Distribution of Parasitized Redfish.

Contour charts of *Sphyrion* distribution in the Gulf of Maine (Fig. 2-5) showed areas of highest parasite incidence on redfish in waters deeper than 130 m, depths where redfish generally are most abundant in this region. To examine depth distribution of redfish in more detail, regressions of percentage incidence of *Sphyrion* on depth of capture of host redfish were calculated for several statistical subareas for 2 recent years when sampling of the redfish catch was extensive (Fig. 11).

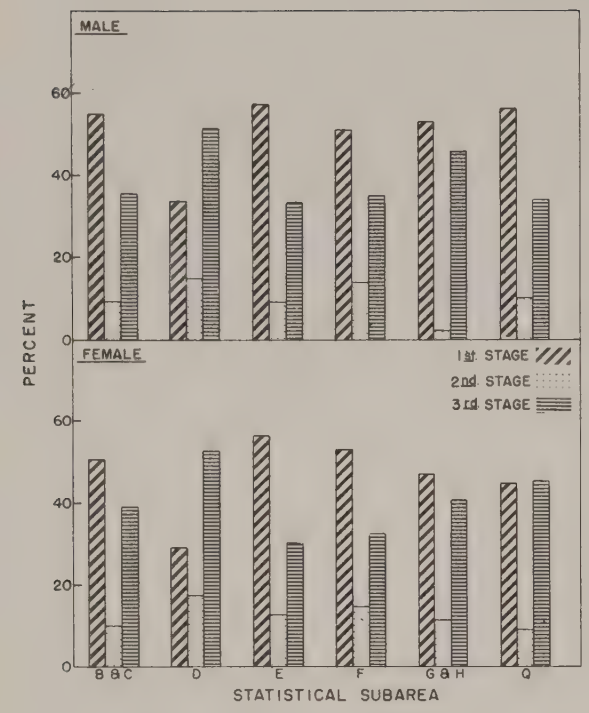

Fig. 6. Percent composition of parasitized redfish having three stages of infestation. Average values for the period 1943-51, by statistical subarea, for males and females separately.

Usually parasite incidence increases with depth, but below 185 m incidence of the parasite diminishes. In all subareas examined, the highest incidence values were distributed through the middle of the depth range, from 120 to 185 m. There is considerable variation in the slopes of the fitted lines, but the mean depth of mean parasite incidence is fairly consistent within the subarea.

Depth distribution of parasitized redfish in the Gulf of Maine is limited by the comparatively shallow depths found there. We confine our interpretation of depth distribution of parasitized fish to this area, realizing that different conditions may prevail on the edge of the continental shelf where redfish occur to much greater depths than in the Gulf of Maine.

7. Variation in Redfish Mean Length and Size Composition.

Mean length of Gulf of Maine redfish, sampled from commercial landings, has shown a gradual downward trend during the last 20 years, and a sharp decrease since 1960 (Fig. 12). Data for males and females show similar annual variations. During most of this period, parasitized redfish have averaged larger than the mean length of the total redfish sample from the Gulf (Fig. 13). Because of differences in size composition of fish in different parts of the Gulf, mean length comparisons

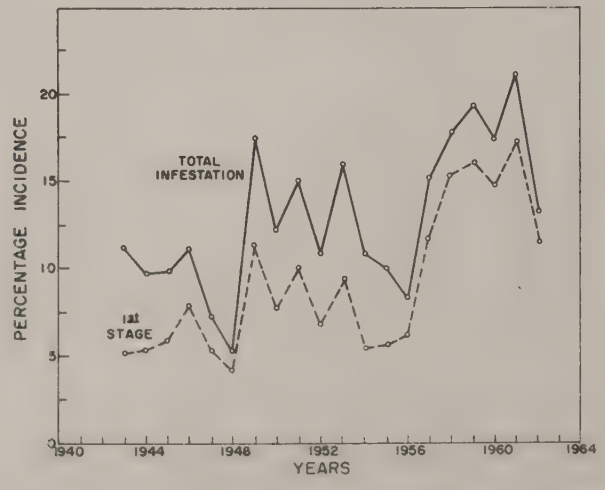

Fig. 7. Variation in annual average percentage incidence of live *Sphyrion* and total parasite infestation on Gulf of Maine redfish, males and females combined, during 1943-62.

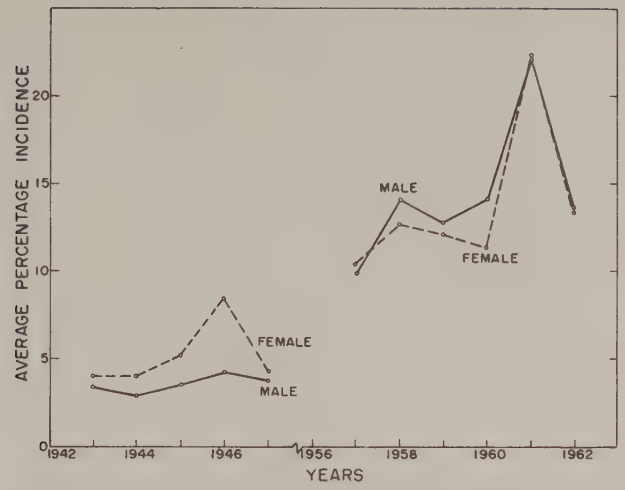

Fig. 8. Variation in annual average percentage incidence of live *Sphyrion* on redfish, males and females separated, in subareas XXII E, F, and G, southern Gulf of Maine, in 1943-47 and 1957-62.

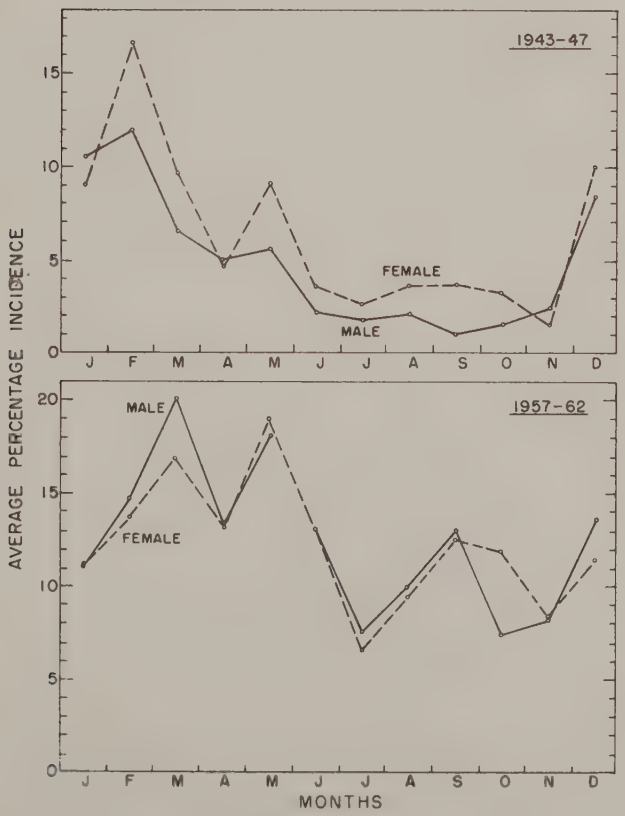

Fig. 9. Seasonal variation in percentage incidence of live *Sphyrion* on redfish in southern Gulf of Maine, subareas XXII E, F, and G. Average monthly values for 1943-47 and 1957-62 are given as percent of each sex parasitized.

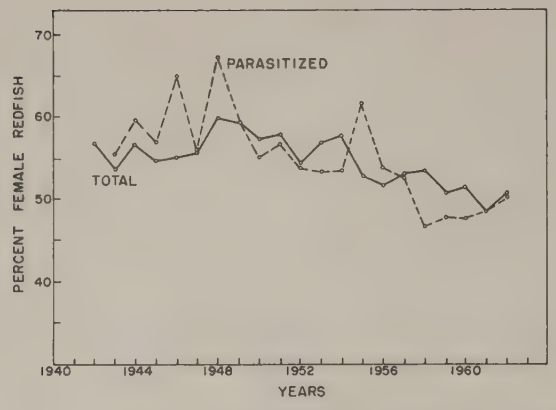

Fig. 10. Annual variations in percentage of female redfish in total Gulf of Maine sample and in samples infested with live *Sphyrion*.

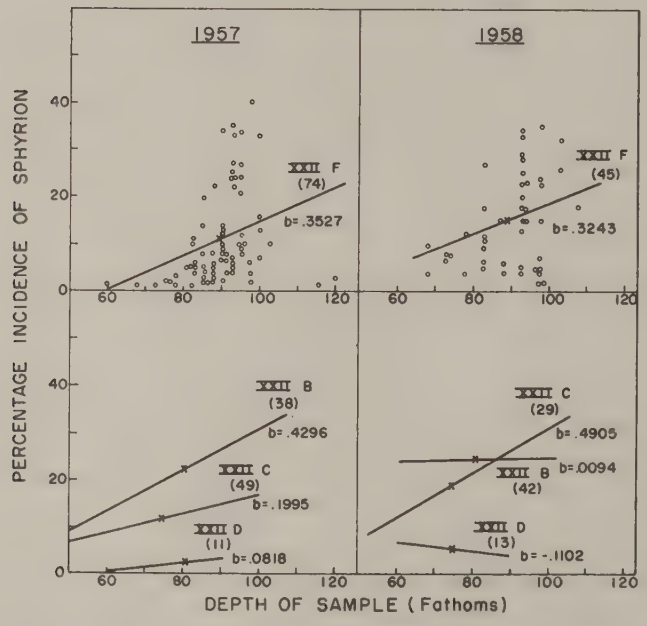

Fig. 11. Regression of percentage incidence of live *Sphyrion* on redfish in relation to depth of capture, by subarea, during 1957 and 1958. Number of samples from each subarea is shown in parentheses.

were made within each statistical subarea, and the results were used to compute weighted mean annual differences for the whole Gulf. Despite differences in length between parasitized fish and the total sample, this relationship has persisted for both male and female fish. Since about 1955, the magnitude of difference has diminished for both males and females. Parasitized females were smaller than the mean length of the total female sample during 1959-61.

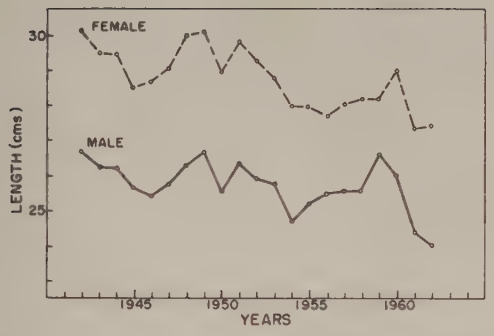

Fig. 12. Variations in mean length of redfish in the Gulf of Maine, 1942-62.

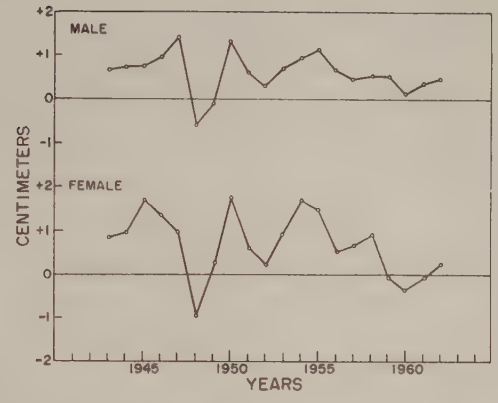

Fig. 13. Difference between annual mean lengths of parasitized redfish and total redfish sample from the Gulf of Maine, 1943-62. Zero lines represent mean lengths of total male and female samples.

Annual variations in mean length of parasitized and nonparasitized redfish are shown best by data from the smaller statistical subareas (Fig. 14). Females are larger than males in all subareas, and local differences in redfish mean length, within the Gulf, are apparent. Recently, a downward trend in mean length in subareas D, E, F, G, and H, was sufficient to offset an upward tendency in subareas B and C, resulting in the overall decrease in mean length in the Gulf shown earlier in Fig. 12.

In all subareas, parasitized redfish were larger than the mean length of total subarea samples during most of the study period. The difference in mean length between the 2 groups has diminished in recent years, especially in subareas B, C, and F, the most heavily fished subareas, where the relationship has been reversed, or nearly so, since 1959. It is noteworthy that, within subareas, the concurrent variations in mean length are similar for males and females.

During the early years of the study, a rather consistent host-size relationship existed among the groups of redfish infested with the 3 stages of parasite infestation (Fig. 15). Average length of parasitized fish was greater than that of the whole sample during most of the years studied. Length relationship of the stages of infested fish was as expected in a time-dependent series of samples where growth of the host was not inhibited by the parasite. Of the infested fish, first stage hosts were smallest, second stage hosts next largest, and third stage hosts were largest. Although Fig. 15 includes data combined for both sexes from all subareas of the Gulf, the resulting relationship suggests that fish infested with each successive stage of infestation averaged about 1 cm larger than those in the preceding group.

A similar host-size relationship is shown in recent average length data from a single subarea (Fig. 16 and Table 4). There is a difference of almost 1 cm between the mean lengths of fish grouped by stage of parasite infestation, males and females separated.

In these data, we have divided first stage infestation fish into groups according to the number of live copepods present on each host in order to compare size compositions of the groups. There is no evidence that size compositions of fish having from 2 to 7 parasites are skewed consistently from the length distribution of fish with only one parasite. There are variations in length-frequencies of multiple infestation groups around the mean of the single infestation group, but it cannot be shown that fish with more than one live copepod parasite are likely to be consistently larger or smaller than those with only a single parasite.

We have rarely seen Gulf of Maine redfish bearing more than 7 parasites. There is an obvious

TABLE 4. LENGTH-FREQUENCY OF NONPARASITIZED FISH AND PARASITIZED FISH, BY STAGE OF INFESTATION, FOR SUBAREA XXII F, 1957-59.

Length cm	Non-parasitized	First Stage Infestation Number of *Sphyrion* 1	2	3	4	5	6	7	Second Stage Infestation (Sores)	Third Stage Infestation (Spots)	Total Sample
MALES											
14	1										1
15	-										-
16	4										4
17	23										23
18	55	2							1		58
19	114	6									120
20	211	4									215
21	278	14							2		294
22	427	29	3						1		460
23	583	48	4		1				2	3	641
24	813	84	10	4	1				5	3	920
25	1,015	134	29	9	5	1			14	15	1,222
26	1,066	162	27	13	2				23	17	1,310
27	912	143	30	6	2	1			31	43	1,168
28	641	85	10	4	1				16	32	789
29	335	33	8		1	1		1	11	17	407
30	124	14	2	1					2	12	155
31	35	7							5	4	51
32	20	2								2	24
33	6	4	1							1	12
34	6										6
35	1										1
Total	6,670	771	124	37	13	3		1	113	149	7,881
Average length cm	25.5	26.3	26.6	26.5	26.3	27.5		29.5	27.2	27.9	25.7
				26.4 cm							
FEMALES											
14	1										1
15	1										1
16	1										1
17	8										8
18	33	1									34
19	87	1			1						89
20	150	3	1								154
21	279	16	3								298
22	312	24	5	1							342
23	382	32	2						1		417
24	411	42	5	1					9	4	472
25	524	65	8	3	1				8	8	617
26	627	71	10	4	2	1		1	5	4	725
27	693	108	16	3	1				9	11	841
28	710	107	15	1	1				14	14	862
29	695	101	15						20	21	852
30	614	85	11	1	1				19	17	738
31	550	80	11	4					21	34	700
32	428	59	5	2					21	22	537
33	409	49	4	3					18	25	508
34	277	38	4	1					19	22	361
35	166	23		2					9	26	226
36	69	9							5	6	89
37	17	5							1	4	27
38	7	2								1	10
39	3										3
Total	7,454	911	115	26	7	1		1	179	219	8,913
Average length cm	28.2	29.0	28.4	29.5	26.4	26.5		26.5	30.9	31.8	28.4
				28.9 cm							

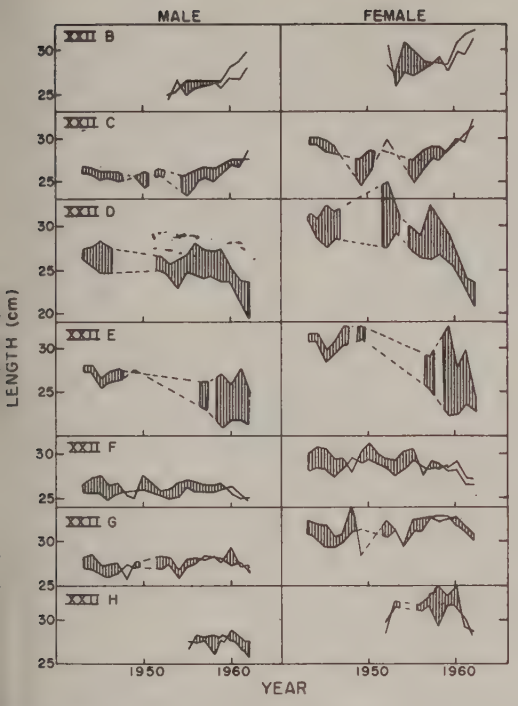

Fig. 14. Variation in mean lengths of parasitized redfish and total redfish sample, by statistical subarea, in the Gulf of Maine, 1943-62. Shaded area represents years when parasitized redfish were larger than the mean length of the whole redfish sample from that subarea.

inverse relationship between number of parasites per host and number of hosts, but we do not know if this represents a level of maximum parasitization that has any biological significance. The number of parasites carried by a host may depend on influences such as physiological factors limiting the density of parasite crowding on the host, mathematical limits governing the parasite's change of finding a host, or the possibility of host mortality caused by parasitization beyond a maximum level. We can only speculate on the relative importance of these factors at this time.

To compare the degree of difference in length-frequencies of parasitized and nonparasitized fish, data from Table 4 are summarized as percent size composition, sexes separated (Fig. 17). The upper portions of the two curves are similar, and the major difference is the comparative lack of small parasitized fish. For both males and females, 96% of the parasitized fish are larger than 22 cm, whereas approximately

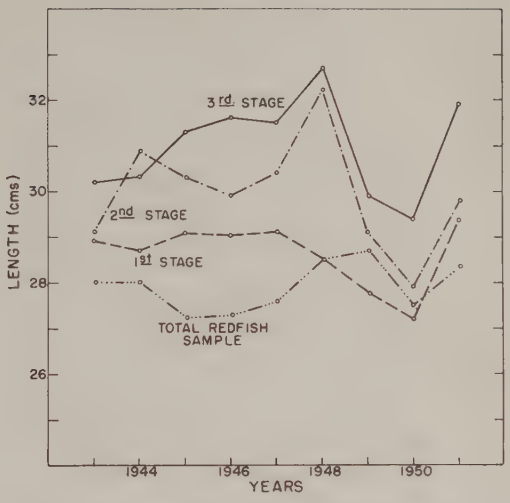

Fig. 15. Comparative annual mean lengths of redfish with first, second, and third stage infestations of *Sphyrion* and that of the total redfish sample from the Gulf of Maine, 1943-51.

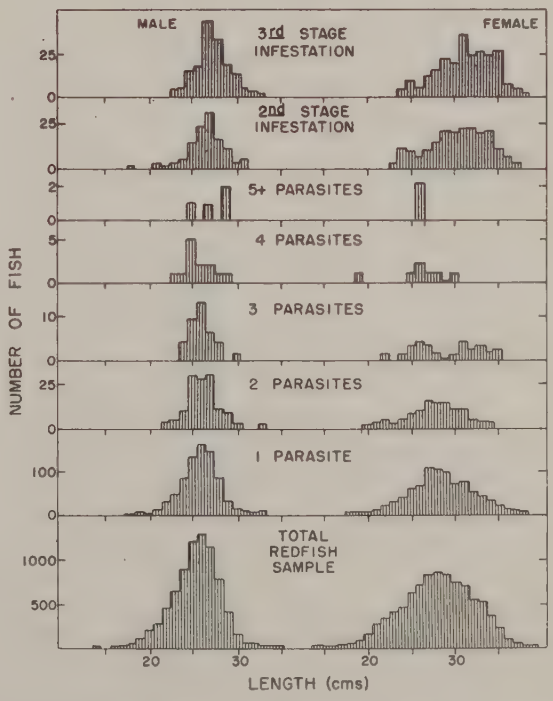

Fig. 16. Comparative size compositions of redfish, grouped as follows: nonparasitized; first stage infestation with 1, 2, 3, 4 and 5 or more live copepods; second stage infestation; and third stage infestation. Data are from statistical subarea XXII F, 1957-59, males and females separated.

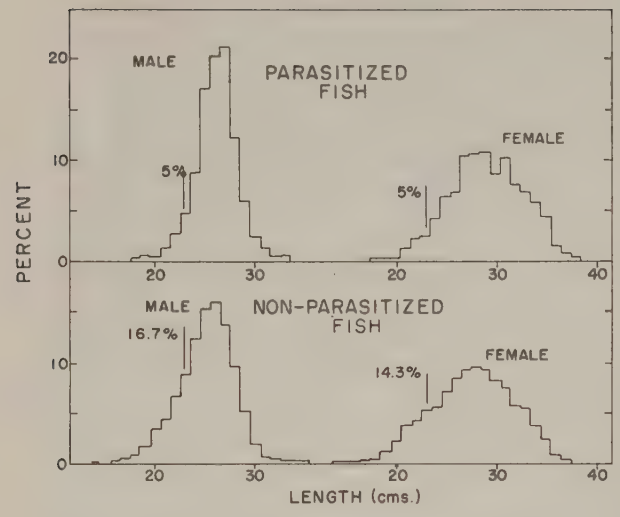

Fig. 17. Percent size composition of parasitized and nonparasitized redfish, sexes separated, in subarea XXII F, 1957-59.

85% of the nonparasitized fish exceed that length. If this difference is attributable to presence of the parasite, the absence of small parasitized fish can be interpreted in two ways: (1) as evidence of specificity of host size for the parasite, of (2) as evidence of small fish mortality caused by copepod parasitization. Whatever the cause, approximately 10% of the fish represented in samples of nonparasitized fish are not present in the size compositon of parasitized redfish.

DISCUSSION

1. Factors Influencing *Sphyrion* Distribution.

A discussion of the effect of *Sphyrion* infestation on redfish is inevitably clouded by our relative ignorance about early life history of the parasite. When *Sphyrion* spawns, how long its larvae are pelagic, whether it infests an intermediate host, how fast it grows, and ho long it lives as an adult, are questions we can not answer. Until direct evidence from the stu of *Sphyrion* life history is available, a degree of speculation about effect of the parasite on its host must be permitted.

The relatively restricted range and stable limits of the Gulf of Maine *Sphyrion* population suggest that it is strongly influenced by hydrographic or ecological factors peculiar to the regic Within this area, the great variability of parasite incidence on redfish indicates optimal conditions for parasite survival in some localities, with very poor or intolerable conditions nearby. There is no evidence that the range of *Sphyrion* is limited by range of redfish, the primary host in this region. Redfish are distributed continuously from the Gulf eastward along the Nova Scoti banks, but the range of the parasite terminates abruptly in the midst of the host stocks.

We agree with Templeman and Squires (1960) that it is difficult to explain the high incidenc of *Sphyrion* on redfish in the widely separated areas of the Gulf of Maine and Hamilton Inlet Bank off the Labrador Coast, with a vast area between where the parasite has never been recorded. The is no published evidence that range of the parasite might depend on the existence of an intermedi host, but this must be held as a possibility that could afford a simple explanation for its discontinuous distribution. While it seems unlikely that two species of *Sphyrion* are involved, taxonomic study of the two parasite populations is necessary before the matter is settled.

Some aspects of Gulf of Maine hydrography suggest that the strictly limited range of *Sphyrio* may be controlled primarily by hydrographic factors. The eastern limit of *Sphyrion* occurrence in the Gulf, shown in Fig. 2 and 3, closely parallels a line where temperature and salinity reach maximum values, and dominant nontidal currents flowing into the Gulf contribute to a counterclock wise gyral called the "Gulf of Maine eddy" by Bigelow (1927). According to Bigelow, the 8°C temp erature and 35.00 °/oo salinity boundaries lie along the eastern edge of the eddy approximately a shown in Fig. 18, representing the maximum northward penetration of slope water into the Gulf. Northwest of these lines, temperature and salinity of bottom water does not exceed those values anytime during the year, except on a few shoal areas close to shore. Waters southeast of the lin are generally warmer and more saline than these limits during much of the year. Aside from rive inflow, the primary source of water entering the Gulf is from the southeast throughout the year, mainly through the Eastern Channel.

It is not suggested that 8°C and the 35.00°/oo represent the maximum temperature and salini in which *Sphyrion* can survive. However, proximity of these maximum lines to the observed bounda of the parasite's distribution suggests these values as likely starting points for seeking limit g environmental factors for the parasite or a possible intermediate host. Since we know so little about the early life history of the parasite, perhaps there is only a short period during the pe gic stage when it is vulnerable to mortality from hydrographic factors, and this period may coin d

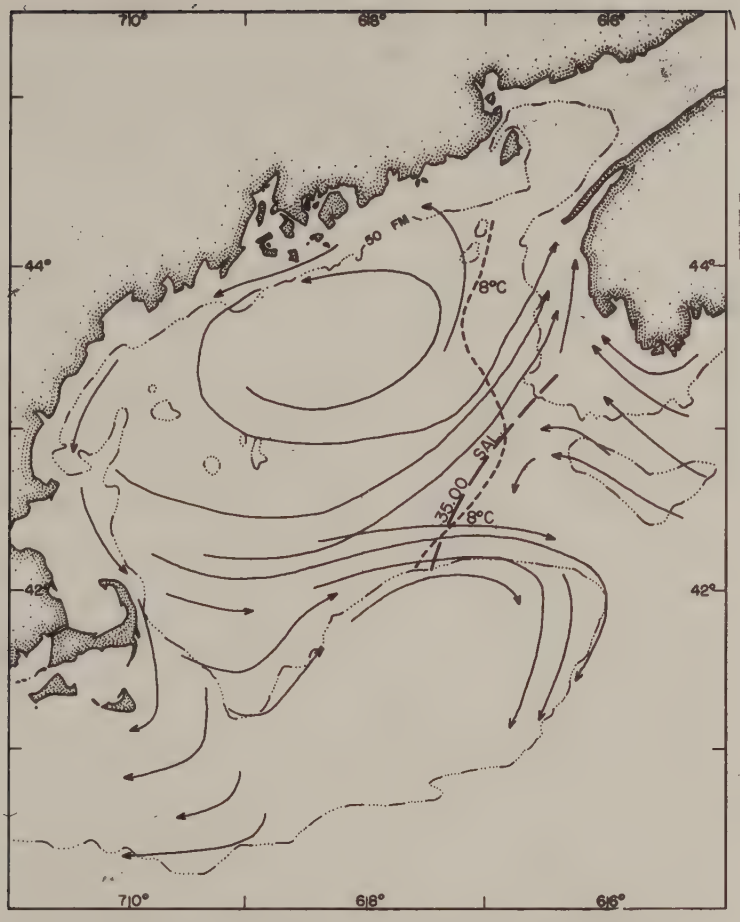

Fig. 18. Approximate location of 8°C bottom temperature and 35 °/oo salinity boundaries representing maximum penetration of ocean water into the Gulf of Maine (Data from Bigelow, 1927).

with a season of rigid hydrographic stability. We cannot discount the effect of inflowing currents around western Nova Scotia which may be sufficient to confine the larvae within the Gulf during this pelagic stage. Any outflow of water from the Gulf is southward around the eastern tip of Georges Bank, or through the South Channel near Cape Cod. *Sphyrion* larvae carried south in this fashion would enter waters where redfish are scarce, and there would be little possibility of finding a host of this species.

2. Changes in Host and Parasite Populations.

Evidence presented above suggests that concurrent changes in the host and parasite populations resulted in a major change in the host-parasite relationship between 1943-47 and 1957-62. The two-fold increase in *Sphyrion* incidence on redfish gives an approximate measure of the parasite population increase. United States landings statistics show that the Gulf of Maine redfish fishery differed greatly during the two periods of intensive study. The 1943-47 period was characterized by heavy fishing effort and high redfish landings; average annual effort of 8,500 vessel-days fished and 97 million pounds of redfish landed. Fishing effort decreased to 3,300 vessel-days per year and landings reduced to 31 million pounds annually during 1957-62. We will not attempt, in this paper, to analyze the complex effects of these changes in rate of exploitation on the redfish stock.

It is sufficient to note that the accumulated redfish stock was comparatively large during the early period and was smaller in the latter period.

The observed changes in redfish sex ratio and size composition probably can be attributed primarily to the effect of fishing. In a population where females initially average about 2 cm larger than males, and outnumber them, otter trawl fishing effort imposes higher fishing mortality on females. Prolonged intensive fishing effort would tend to equalize the sex ratio and minimize differences in size composition between sexes, resulting in changes such as we observed.

3. Effect of Parasite on Host.

Several aspects of the host-parasite relationship suggest that the parasite harms its host. The relative abundance of the three stages of infestation, differences between size of nonparasitized fish and those having the three stages of infestation, and seasonal variation in parasite incidence all indicate that *Sphyrion* infestation may kill some fish.

Although we do not know the longevity of the parasite, a difference of 1-2 cm in average length between fish groups infested with each stage indicates that each successive group, based on our knowledge of redfish growth, is about 1 year older than the preceding one (Fig. 15). This means that an average female parasite is about one year from the time it is first visible to the unaided eye until it attaches, dies, or is removed from the host. Since many of the parasites are broken off, it is likely that an unmolested parasite lives considerably longer, perhaps two years or more.

The second stage of infestation is least numerous and, therefore, is probably shorter than the other two stages. Since it is, by definition, a transitory stage, perhaps only a few weeks are required from the time a copepod is broken loose until the wound has healed. From what we have observed the third stage has potentially the longest duration. Heads of the parasites are so deeply and firmly embedded that usually they become encysted in the flesh when the wound heals. These cysts apparently persist for years in a healthy host.

Relative numbers of fish parasitized with each stage of infestation, and the approximate duration of each stage, may indicate the probable rate of survival of parasitized fish through the three stages. Assuming that the second stage is shorter, and the third longer, than the first stage then, after several years of parasitization, the third stage should be about as abundant in the population as the first. Since the third stage is less numerous than the first, fish with encysted parasite remains either remove the cysts, or die. It seems unlikely that cysts can be absorbed completely by surrounding tissue, or can be discharged from the tissue as matter from a festering sore, but this is possible. Redfish natural mortality may be sufficiently high to cause this reduction, but *Sphyrion* infestation probably kills many fish.

The great difference in winter and summer parasite incidence is not what would be expected of a long-lived and durable parasite such as *Sphyrion* appears to be. Highest incidence in late winte suggests a single spawning period in early winter with infestation immediately thereafter (Fig. 9) Reduction of about 50% in numbers from winter to summer indicates either a high removal rate of parasites from the host, or, as was mentioned earlier, a high mortality rate of parasitized fish.

Removal of *Sphyrion* could result from at least three causes: (1) natural mortality of the parasite, (2) abrasion by the host, or (3) predation by fish or invertebrates. There is no evidence that redfish are involved in commensal parasite-removal relationships with other animals, but similar relationships have been shown in reef fish communities (Limbaugh, 1961), and may occur here. Perlmutter (1951) proposed abrasion by the host as the major factor controlling position of the parasite on Gulf of Maine redfish. This proposal is debatable since it does not apply to the Hamilton Inlet Bank and Eastern Grand Bank areas where a different pattern of infestation suggests either different environmental conditions,or, perhaps, different genetic characteristics of the parasite stocks (Templeman and Squires, 1960). Natural mortality of *Sphyrion* is not likely to be high enough to account for the entire reduction in parasite incidence. Each of the three factors mentioned may contribute partially to the reduction in numbers of parasitized fish, but mortality of the host due to infestation is a probable cause of seasonal reduction in parasite incidence.

Difference in size between parasitized and non-parasitized redfish is one of the most obvious effects of infestation, but the reasons for this difference are not clear. Aside from variations in growth rate of the host, three factors could change the size composition of one or more of the groups of fish infected with the three stages of infestation. (1) Duration of parasite recruitment year? (2) Minimum length of host that *Sphyrion* will invade, and (3) Whether the parasite kills its host, either directly or indirectly.

We showed earlier that infestation of the host probably occurs in late winter. Assuming that ıfestation occurs only then growth of parasitized fish will steadily increase the mean length of ıat group during the remainder of the annual cycle, with no recruitment of smaller sizes of ırasitized fish to the group. Nonparasitized fish also will grow during that time, but small fish .ll join the group, causing the mean length of nonparasitized fish to be less than that of the ırasitized fish. The influence of this factor can account only for the difference in size com- ɔsition between nonparasitized fish and first stage parasitized fish, and does not apply directly ɔ differences between the three stages of infestation. However, since the three stages of infes- ıtion proceed in time then fish surviving to the later stages are larger than fish comprising pre- ɛding groups assuming that growth of surviving parasitized fish is not inhibited. Continuing this ɔocess for several years would result in size differences similar to those observed in the Gulf f Maine redfish population, but this factor alone may not account for the magnitude of difference, r the relative degree of skewness, shown between size compositions of redfish having the three ɪages of parasite infestation.

If *Sphyrion* infests only fish larger than a specific size, then this factor alone accounts for ırasitized fish being larger than nonparasitized fish, and there is no need to speculate about ɔssible mortality of the host due to parasite infestation. However, there is neither experimental vidence that *Sphyrion* requires a certain size host, nor that it is influenced by secondary factors ɛlated to size or maturity of its host. If the parasite requires only a supply of blood to survive, ıen it is probable that all sizes of redfish are attacked, and many infested small fish weaken and ɪe. Since *Sphyrion* can grow to a length of 6 cm, it is conceivable that fish smaller than 20 cm re unable to survive the stress of a growing parasite.

CONCLUSIONS

The hypothesis that redfish mortality may be caused by *Sphyrion* infestation is supported largely y fragmentary evidence. No single aspect of the parasite's incidence proves that it kills its ɔst, but the aggregate effect suggests that it does. Many of the changes in the redfish population ight be results of mortality caused by parasitization, but there are equally plausible alternative xplanations. If *Sphyrion* attacks redfish smaller than 20 cm long the relative scarcity of para- itized fish in that size group suggests that parasite infestation may kill many small fish.

From evidence shown in these gross studies of *Sphyrion* incidence on redfish, we conclude that ıe parasite is sufficiently important in the Gulf of Maine fishery to deserve more detailed study f its relationship to redfish. Investigation of *Sphyrion* life history and environmental factors ıfluencing its distribution must be given high priority.

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Pathology of the Northern Fur Seal

Mark C. Keyes, D.V.M.

Summary

Nearly half a million fur seals (*Callorhinus ursinus*) are born each year on the Pribilof Islands, Alaska, but as few as 10% may survive to be harvested at age 2 to 5 years. The known or suspected causes of mortality at sea, where most deaths occur, are predation, starvation, weather, parasitism, food poisoning, and infectious diseases. The major known causes of the 5 to 20% mortality of pups on land are malnutrition, trauma, parasitism, and gastrointestinal and miscellaneous infections.

Marine mammals are divided into 3 orders: Carnivora, Pinnipedia, and Cetacea. The order Carnivora is represented by the sea otter; Pinnipedia by the seals, sea lions, and walrus; and Cetacea by whales, dolphins, and porpoises.[17] These animals have become more frequent objects of research. For example, scientists are now trying to find out how the Weddell seal (*Leptonychotes weddelli*) can remain submerged as long as 40 minutes, and how it employs sonar to locate underwater objects for feeding and navigation.[15] Scientists might well be interested in the diet of the fur seal and gray seal pups (*Halichoerus grypus*), because the fur seal's diet consists of milk that is over 50% fat, and the gray seal, the mother transfers about 60 lb. of blubber to her pup in only 18 days.[1,9] How are such large quantities of fat handled without causing arterial disease? Space physicians might profit from study of the walking seals, since the reaction of the marine mammalian heart to increased terrestrial activity without the assistance of buoyancy of sea water may parallel the reaction of an astronaut's heart to normal activity after a long period of weightlessness.

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Adapted from a presentation given before the Section on Research, 102nd annual AVMA meeting, Portland, Ore., July 11-15, 1965.

Veterinarians in Marine Research

Few veterinarians are retained full-time for marine mammal research, but veterinary educational institutions and private practitioners are occasionally consulted. Because of the increasing number of marine mammal exhibits in zoos and aquariums, more veterinarians are becoming familiar with these animals.

The 120 species[17] of marine mammals contribute to world economic wealth through a variety of products. If these species are to be successfully conserved and utilized, their population dynamics must be understood. A thorough knowledge of natural mortality is necessary to that understanding. The participation of a veterinarian in the program of conservation and maximum use of fur seals is part of one step into a coming field in veterinary medicine—wildlife conservation and marine research.

History of the Fur Sealing Industry

The fur sealing industry dates back nearly 200 years, when the Pribilof Islands were discovered by the Russian explorer Gerassim Pribilof. After the purchase of Alaska by the United States, the islands were leased by private companies for 40 years, during which time nearly 2½ million seals were killed on land.[2] These harvests, combined with pelagic sealing, reduced the herd to a dangerous low of an

estimated 216,000 animals.[2] Under an international ban on pelagic sealing in 1911 and conservative harvesting by the U.S. Government, the fur seal population recovered by 1940 to an estimated 1½ million.[2] About 60,000 seals are now being taken annually. The most popular class of processed seal furs, determined by color, size, and grade, sold for an average of $122.03 per skin. The top price was $161 at the 1965 spring sale.

Nearly half a million fur seals are born each year on the Pribilof Islands; as few as 10% or less may survive to be harvested at ages 2 to 5 years. Causes of mortality and pathogenetic factors are of primary concern to wildlife management biologists. The U.S. Fish and Wildlife Service (and its predecessor agency) has sponsored or cooperated with several groups of investigators since the late 1800's.

History of Research on Fur Seal Mortality

Causes of death in fur seals were studied in 1896-1897 when most pup mortality was attributed to trampling by bulls.[6] After discovery of the hookworm (*Uncinaria lucasi*) in late 1896, the primary blame was shifted to uncinariasis; starvation was rated second and trampling third.[6] Only gross postmortem examinations of dead pups were conducted.

According to results of postmortem examinations in 1906, a high incidence of asphyxia neonatorum was reported among newborn pups.[12]

Mortality studies after 1906 were limited to annual counts of dead pups on land in 1941 and 1948 to 1950, until 1951, when the first of 9 summers of hookworm investigations was begun. It was discovered that infective hookworm larvae reside in the blubber until parturition and are transmitted to the pup in the milk during the 1st nursing.[11]

Also in 1951, investigators isolated *Salmonella enteriditis* from 5 of 12 fur seal pups and from the sucking lice on 1 pup.[5]

In 1957, it was reported that 98.6% of 1,727 deaths in pups were caused by hookworms or starvation.[3]

Psittacosis-group antibodies were found in fur seal serums in 1960 and 1961, but an associated clinical syndrome was not recognized.[18]

Mortality of Fur Seals at Sea

The principal known or suspected causes of mortality in seals at sea are predation, starvation, weather, parasitism, food poisoning, and infectious diseases. The relative importance of mortality at sea is unknown, but it is believed to have the greatest impact on recently weaned pups as they begin their adaptation to a strictly pelagic existence in November.

Predators.—Known predators of fur seals are the killer whale (*Orcinus orca*) and the white shark (*Carcharodon carcharias*).[2] It is possible that other sharks prey on fur seals, particularly pups. The number of fur seals killed by predators is not known.

Starvation and Weather.—Scarcity of food, physical impairment from injury, old age, infection, and storms are factors which may contribute to starvation. Prolonged storms may kill weaker seals through exposure, fatigue, drowning, and interruption of feeding.

Parasitism.—As soon as pups leave the rookeries and change their diet from milk to fish, they begin to accumulate the ascarids, *Phocanema decipiens* and *Contracaecum osculatum*, which attach primarily to the gastric mucosae. A typical lesion consists of a small ulcer, 1 to 5 mm. in diameter, surrounded by a swelling to form a crater in which the anterior ends of one to several immature worms are buried. As many as 400 worms may be distributed in this fashion throughout the stomach. Occasionally, nests of larvae may be found within thick-walled gastric carbuncles up to 40 mm. across and 10 mm. thick. The larvae may also penetrate the stomach wall and cause peritonitis. Eighty-five larvae were found free in the abdominal cavity of an 8-month-old fur seal.[13] The extent of mortality from ascarid infection is not known but it may be great, since the incidence of ascarids in fur seals approaches 100%. Of 1,355 seals taken at sea in 1963, all but 4 were infected.[9]

Other fish-borne parasites include ces-

todes, trematodes, and acanthocephalans. The cestodes, *Diphylobothrium pacificum* and *Diplogonoporus sp.*, and the acanthocephalan, *Corynosoma strumosum*, can often be found in greatest numbers at the ileocecal junction. The trematodes, *Pricetrema zalophi*, *Phocitrema fusiforme*, and *Cryptocotyle jejuna*, inhabit the small intestine. More than 1,000 *P. zalophi* were found in 1 seal.[13] It is of particular interest that, although fur seals are known to feed on salmon to some extent, the fluke of salmon poisoning, *Troglotrema salmincola*, has not been demonstrated. The importance of cestodes, trematodes, and acanthocephalans in mortality of seals at sea has not been evaluated.

Only 2 of the 4 known ectoparasites of fur seals are a factor at sea: the nasal mites, *Orthohalarachne diminuata* and *Orthohalarachne attenuata*. The 2 species of sucking lice are primarily a problem on land. Infestation of the nasal turbinates with mites is frequently massive in pre-adult and adult seals. It is possible that breathing (especially at sea) could be critically impaired.

Food Poisoning.—From time to time, large numbers of seals are reported dead, floating in the water or washing ashore, with no obvious lesions or cause of death apparent. In September, 1962, for example, approximately 275 seals and numerous birds and foxes were found dead along the beaches of St. George Island. The circumstances pointed to a toxin in food common to seals and birds and also affecting foxes scavenging the recently dead animals. Remnants of sand lance (*Ammodytes hexapterus*), a food fish of seals and sea birds, were found in the intestines of dead seals and birds. The shells of small pelagic snails were found in the intestines of seals and in the intestines of sand lances regurgitated by a sea bird. These findings suggested the possibility that pelagic snails contaminated with a toxin (dinoflagellate) were ingested by sand lance; and that the fish, in turn, were consumed by seals and sea birds in the vicinity of St. George Island; and the dead seals and sea birds were scavenged by the foxes.

Parts of fish, seals, birds, and foxes were fed to white mice, and seal stomach contents were injected into other white mice, with negative results. If there had been a toxin, however, it could have been inactivated by a change in pH prior to freezing the carcasses or by the 5 months of cold storage in transit from the isolated island.

Infectious Disease.—It is unlikely that an epizootic, dependent on transmission from seal to seal, could occur in the ocean, since fur seals do not congregate there, nor do they come ashore except at the breeding grounds. Epizootics at sea must therefore be a result of either a long incubation period of an agent contracted on the breeding grounds or an agent transmitted in the food. The agent of salmon poisoning disease qualifies for the latter mode of infection, but it is not known if fur seals are susceptible.

Mortality of Fur Seals on Land

The cause and spread of disease among fur seals on land is intricately involved with their biologic processes and life cycle. Fur seals spend most of the fall, winter, and early spring in the water of the northern Pacific ocean, ranging from 50 to 100 miles offshore as far south as southern California.[7] They return to the Pribilof Islands in the order of decreasing age, starting with the mature harem bulls in May and ending with the youngest females in October.[2] Some bulls are killed in battles over territories, and some females are killed by bulls trying to retain them. The percentage of females that die from complications of dystocia is not known. Mortality of pre-adults from natural causes is slight on land.[2] Most fur seals that die on land are pups. In 1956, 120,000 dead pups were counted.[16] This mortality represented 12% of an estimated 992,000 pups, from birth to the age of approximately 2 months.[16] Fewer than 19,000 males were harvested from this year class during the ensuing 5 years.[16] If a male escapement of 10% and a 1 to 1 sex ratio are assumed, the total natural mortality of the year class to age 5 years was 96%. In 1958, the count of dead pups was 38,000, of an estimated 729,000 born—a land mortality of 5.2%.[16] Correspondingly, over 80,000 males were harvested from this year's class,

suggesting a combined land and sea mortality of 75% to age 5.[16] Such wide fluctuations in mortality are not unusual for a wild animal population of this size. The combinations and magnitudes of variables contributing to these fluctuations are many and great.

However, mortality of the newborn is one area that can be scrutinized, although it presents many problems. Rookeries where pups die are usually inaccessible except from catwalks, because of the belligerent attitude of both adult males and females congregated in contiguous harems. Idle bulls, equal in number to harem bulls, surround the harem areas waiting for the opportunity to acquire a harem, and further impede access to the rookeries.

Mortality of Fur Seal Pups

An understanding of the environment of pups is necessary for an accurate interpretation of postmortem findings. Although the bulls confine their movements to territories established before the females arrive, their patrolling of boundaries, along with movement of females and pups to and from the water, results in continuous chaos. Consequently, the pups are frequently trampled accidently by the bulls and are treated roughly by all but their own mothers.

To avoid contact with adult seals, pups congregate in pods, where there is a free exchange of ectoparasites and other potential disease agents.

The rookeries serve not only as a place for parturition and copulation, but also as summer graveyards and "sewage disposal areas" for a breeding population of about a million seals. During the breeding season in July and August, the weather ranges from occasional warm sunshine to chilling wind-driven rains and is otherwise foggy or misty. There are many areas of poor drainage which become contaminated with excrement and dead seals, and through which large number of seals, particularly pups, may flounder.

When pups nurse for the first time they are likely to ingest hookworm larvae in the milk. When nursing periods become increasingly less frequent, up to an average of 8 days apart, pups must shift for themselves while their mothers swim hundreds of miles in search of food.[4] It is common for a pup to miss one or more nursing opportunities if he has wandered too far from the site to which the mother customarily returns.[14]

During the past 3 seasons, 226 fur seal pups have been necropsied, but the findings most likely representative of the pup population were from 109 pups collected throughout the 1964 season from the same zone of 1 rookery. Pup mortality was complex; 18 primary and 30 secondary and tertiary causes of death were found. The major categories of primary causes were malnutrition, trauma, parasitism, miscellaneous infection, and gastrointestinal infection.

Malnutrition.—Malnutrition was the primary cause of death in 37.6% of the 109 pups and secondary cause in 5.5%. The condition was characterized by a paucity of subcutaneous blubber; atrophic, dark red muscles and liver; atrophy of the thymus and lymph nodes; empty gastrointestinal tract; and often saccular areas in the jejunum and ileum. The saccular areas ranged from thin and atrophic, containing yellowish brown fluid, to distended and necrotic, containing black tarry material. The blood was dark, viscous, and poorly coagulated. The skin lacked resiliency, and all the tissues had less fluid than normal. The adrenal cortices were very thin and depleted of lipid.

The major cause of malnutrition is probably prolonged separation of mother and offspring. Other possibilities are agalactia, mastitis, starvation, or other diseases in the mother which inhibit milk production, and diseases in the pup which prevent or inhibit nursing. Malnutrition occurred most frequently in combination with gastrointestinal infection, often with trauma or uncinariasis, and sometimes with all 3. General and pulmonary passive congestion and respiratory failure were the terminal events, but infection, trauma, and parasitism hastened the process.

Trauma.—Traumatic lesions were found in 36.7% of the pups and were the primary cause of death in 17.4%. The lesions con-

sisted of fractures, contusions, and bite wounds, usually of the head and neck. Bite wounds frequently penetrated the skull, causing meningoencephalitis and hemorrhage. Bites of the thorax, abdomen, or limbs resulted in pleuritis peritonitis, and cellulitis, respectively. The bacteria associated with these infections were *Streptococcus faecalis, Escherichia coli, Aerobacter aerogenes, Clostridium perfringens,* and *Proteus mirabilis.* Another organism tentatively identified as *Actinomyces sp.* and an unidentified anaerobic, gram-negative filamentous rod were also isolated. Trauma seemed less prevalent when the majority of pups began congregating in pods away from adult seals.

Parasitism.—The hookworm, *U. lucasi*, an important cause of death in fur seal pups, is the only nematode known transmitted in the milk. Pups acquire infective larvae the 1st day of nursing but not subsequently.[11] The prepatent period is 13 to 14 days, and the eggs take about 25 days to hatch.[11] New-generation larvae appear in the belly blubber of pups about mid-August, and the adult worms are gone from the intestine about mid-September.[11]

Uncinariasis was the primary cause of death from hemorrhagic anemia in 13 (12%) pups and a secondary or tertiary cause in 13 others. Altogether, hookworms were detected in 42 pups (38.5%). By mid-August, when the prepatent period of the larvae has passed for most of the pups, the incidence of hookworms may be higher. Acute uncinariasis was characterized by extremely pale organs, watery blood, and usually over 100 worms and free blood in the small intestine and colon. The liver was often fatty, and the small intestines had a nodular appearance. The victims were frequently large, heavy with blubber, and in good condition, except for appearing like freshly slaughtered and well-bled animals.

Pups were also parasitized by the sucking lice, *Antarctophthirus callorhini* and *Proechinophthirus fluctus*, and the nasal mites, *O. diminuata* and *O. attenuata.* Infestations were usually mild and probably unrelated to serious illness or death; however, some severe louse infestations have been noticed (15 lice per square inch of body surface).[8] These parasites are capable of carrying infectious agents such as *Salmonella*[5] and perhaps endoparasites such as the microfilariae of the tunic worm, *Dipetalonema spirocauda.* The adult filariids are in the subcutaneous tissue, particularly of the scrotum, in immature and adult seals. Microfilariae were found in the serums of 35 of 40 harvested males.[9]

Miscellaneous Infection.—Infections of several types were prevalent in fur seal pups; omphalophlebitis, peritonitis, pleuritis, abscesses, and phlegmons were the most numerous. These infections were usually sequels to bite wounds and were the primary cause of death in 11.0% of the pups and a secondary cause in 16.5%. Bronchopneumonia was surprisingly rare—only 1 case in 109 pups.

Gastrointestinal Infection.—The morbidity of gastrointestinal infection (44.0%) was much higher than the mortality from that cause (4.6%). Necrotic enteritis was the most common form, making up half the cases, followed by catarrhal enteritis and hemorrhagic enterocolitis. The bacteria cultured from small intestines were *E. coli, P. mirabilis,* and *S. faecalis.* Organisms isolated from heart blood were *E. coli, C. perfringens,* and an anaerobic, gram-negative filamentous rod not yet identified. In addition, *Paracolobactrum intermedium* was isolated from a specimen of focal necrotic hepatitis.

Need for Further Research

Further progress in understanding fur seal pathology must be based on a diversified program. This program includes developing a method of holding normal seal pups under controlled conditions for observation and experimental inoculation, physiologic and anatomical studies of seals of various ages to establish a basis for recognizing and understanding the abnormal, and postmortem examinations to recognize disease syndromes and determine their cause.

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EFFECTS OF THE MARCH 27 EARTHQUAKE UPON THE SHELLFISH RESOURCES OF ALASKA

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Between June 8 and June 24, 1964, a general survey was conducted to learn the effects of the March 27, 1964, earthquake upon shellfish populations and their habitats. Fishermen, packers, state management personnel, and others were visited in Cordova, Anchorage, Seldovia, Homer, Kasitsna Bay, Kodiak, Olga Bay, Sand Point, and Squaw Harbor. Razor clam beaches also were visited at Cordova, Ninilchik, Poly Creek, and Swickshak. The area affected by the earthquake has been estimated at more than 30,000 square miles. More than 22,000 square miles located east of the tectonic hinge-zone subsided and at least 12,000 square miles located west of this zone uplifted. The major effect on shellfishes occurred near Cordova. Razor clam beaches rose about six feet in the Copper River area; butter clams (Saxidomus nuttallii) and cockels (Clinocardium nuttallii) were found dead on exposed beaches in Orca Inlet after the quake; and submarine landslides may have caused mortality to shellfishes in western Prince William Sound where several square miles of dead rockfish (Sebastodes sp. and Sebastolobus sp.) and cod (Gaddus sp.) were observed on on March 28, 1964. Other razor clam beaches were probably not affected since these areas were not uplifted or lowered greatly by the earthquake. Subsidence of the area which includes Kasitsna Bay will reduce the availability of butter clams there by about 80%. There was no evidence of mortality of king crab, shrimp, and dungeness crab or major changes in their habitats except possibly in the Prince William Sound area.

Reprinted from

SCIENCE IN ALASKA

1964

Proceedings
Fifteenth
Alaskan Science Conference
College, Alaska

August 31 to September 4, 1964

Edited by George Dahlgren

Published by
ALASKA DIVISION
AMERICAN ASSOCIATION FOR THE ADVANCEMENT
OF SCIENCE

March 15, 1965

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Growth and carbon metabolism of euphausiid crustaceans.

Techniques for the laboratory study of euphausiid crustaceans, dominant members of the deep sea plankton, have recently been developed (Lasker and Theilacker, Limnol. and Oceanogr. 10:287, 1964). Growth, respiration, carbon assimilation and incorporation were determined on laboratory raised individuals. Maximum growth of juvenile *Euphausia pacifica* was 0.044 mm/day for 4.5 to 8.5 mm; field data indicate that growth over two years life span averages 0.027 mm/day. Molting occurs every five to six days at 10°C, and faster at high temperatures; respiration averages 1.47 μl O_2/mg dry wt./hr regardless of the animal's weight (100 determinations). Respiration and molting account for the major loss of assimilated carbon, approximately 70% and 10% respectively. Total incorporation of carbon into tissue was high in young rapidly-growing animals, about 25%, but was as low as 6% in some animals. The population incorporated about 9% of the carbon ingested over its life span.

Abstract No. 395. American Zoologist, Vol. 5, No. 4, November, 1965, p. 706

THE PHYSIOLOGY OF PACIFIC SARDINE EMBRYOS AND LARVAE

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INTRODUCTION

The purpose of this paper is to review the present state of knowledge on the physiology of sardine eggs and larvae, to show the relationship between the developing larva and its yolk supply, and finally to offer some deductions on what the available food supply for larvae must be after the yolk supply is exhausted.

GENERAL BIOLOGY OF THE SARDINE EGG AND LARVA

The sardine egg after fertilization is planktonic, has a chorion about 1.7 mm in diameter, a perivitelline space containing sea water and a spherical yolk sac about 1 mm in diameter. The chorion is freely permeable to water, salts and respiratory gases (Lasker and Theilacker, 1962). The yolk mass and developing embryo is less dense than the chorion and floats within the subchorionic space abutting the inside of the chorion at the top. During stage XI (see Ahlstrom, 1943 for stage descriptions) with development of the embryonic tissue and the concomitant utilization of the light yolk the entire egg sinks. This sinking period (depending on the temperature and density of the water) can be as long as 2-3 hours and at a rate of about two meters per hour whereupon the animal hatches out, probably by utilizing a hatching enzyme. Unencumbered by the heavier chorion the larva floats upward. At this stage the sardine larva lacks a mouth, an open gut, gills, pigment in the eyes, and its organ systems are virtually undeveloped. An electron micrograph (Threadgold and Lasker, unpublished) of the skin of the newly hatched larva is shown in Figure 1. The entire skin is composed of two cell layers, is 1.7μ thick in the fin-fold region, and 3μ in the main body region. In cross section each cell of the outer layer has an internal densely staining rod-shaped structure which may be the precursor of the true scale. There are structures in the outer cell layer which suggest a secretory function for the epithelium but an analysis of the role of subcellular structures in osmoregulation is yet to be done. As the larva develops (at 15° C for example) the mouth begins to form at 162 hours post-spawning and the gut opens four hours later. At this point the bulk of the yolk has been consumed and only a trace remains. Fully pigmented eyes and a movable jaw are complete at approximately 170 hours and the last trace of yolk is utilized seven hours later. At first opening the gut is 40μ in diameter and can be distended to 100μ the following day with food. In dense suspensions of unicellular algae (e.g. *Platymonas subcordiformis*) larvae with their intestines fully opened rapidly fill their gut by swallowing.

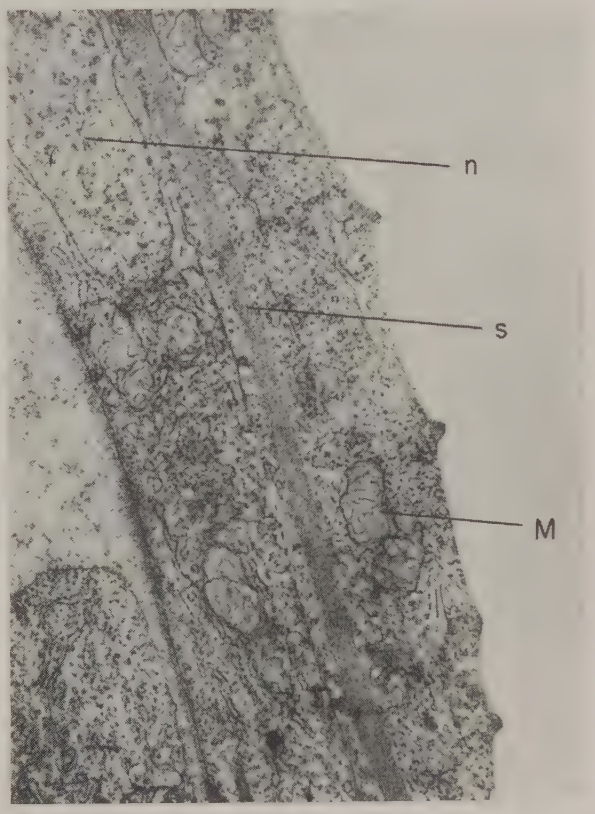

FIGURE 1. Electron micrograph photograph of a cross section of larval Pacific sardine skin. M, mitochondria; n, nucleus; s, scale anlage (?) photo by Dr. L. T. Threadgold, Queen's University, Belfast, Ireland). Larval skin is approximately 3 μ across.

ENERGY REQUIREMENTS

During development, as organized tissue is added, there is a gradual but definite increase in oxygen uptake (Fig. 2) and at the time the yolk is completely consumed the animal has its highest basal rate. Swimming movements are frequent and cause an increase in respiration. A balance sheet has been

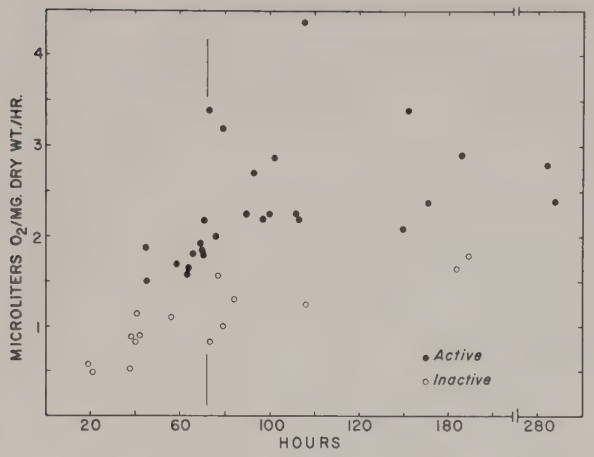

FIGURE 2. Q_{O_2}'s of active and inactive Pacific sardine eggs and larvae (14° C). The vertical line at 72 hours indicates time at hatching. Each dot represents an individual egg or larva. (Lasker and Theilacker, 1962).

constructed (Table 1) which shows that at 14°C the sardine larva metabolizes at a steady high rate and reaches a point where there is not enough yolk remaining to provide all the energy needed. This time is approximately 10 hours prior to complete eye pigmentation and development of the functional jaw. Conversion efficiency of the yolk to somatic tissue over the entire yolk sac period is high (78 per cent at 14°C), and may be greater at slightly higher temperatures (16° C) if the attainment of maximum length is taken as the criterion (Fig. 3). Calculations of efficiency with time over the developmental period show that conversion efficiency declines as the embryo grows older (Table 2) and a greater proportion of the energy available is used up in catabolic processes.

Since the yolk supply is presumably ideally suited to the metabolic and growth needs of the embryo and larva, it should be possible to deduce from information of the energy value of yolk and the meta-

TABLE 1

AVERAGE YOLK UTILIZATION BY SARDINE EMBRYOS AND LARVAE AT 14° C EXPRESSED AS DIMINISHING VOLUME AND CALORIC UPTAKE

(Lasker, 1962)

Elapsed hours from spawning	Yolk volume (mm^3)	Calories remaining	Catabolic calories
0	0.56	0.300	0
42	0.48	0.260	0.0063
71	0.29	0.160	0.0096
80	0.25	0.130	0.0040
100	0.16	0.085	0.0088
120	0.09	0.048	0.0088
140	0.04	0.021	0.0088
160	0.01	0.005	0.0088
180	0	0	0.0088
		Total	0.064

$$\text{Per cent efficiency} = 100 \times \frac{0.300 - 0.064}{0.30} = 78.7\%$$

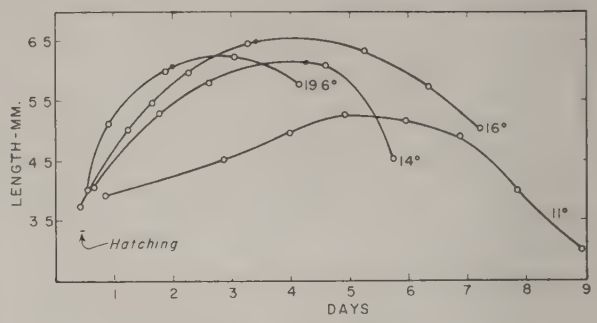

FIGURE 3. Increase in length of sardine larvae at four different temperatures. (Lasker, 1964).

bolic requirements of sardine larvae at yolk sac absorption, the food requirements of the larva when it begins to feed. Knowledge of the Q_{10} of yolk absorption (i.e., the relative rates over a span of 10°C) permits these calculations to be made for a range of environmental temperatures.

The caloric value of a sardine egg yolk of 0.56 mm^3 averages 0.3 calorie and at 14°C this is consumed in 180 hours (Lasker, 1962). Table 1 also shows the calorie requirement for catabolism by a sardine larva with time. The remainder of the yolk is utilized for growth. During the last day of yolk absorption the animal continues its high rate of metabolism but there is less yolk energy available than the catabolic demand. To maintain the same catabolic rate with no growth, the larva must eat and digest the caloric equivalent of 4.4×10^{-4} cal/hr. If the same caloric uptake is needed that was supplied by the yolk, the larva must ingest the equivalent of 17×10^{-4} cal/hr.

Food organisms taken by 4–6 mm sardine larvae range in cross sectional diameter from 25–125μ and are chiefly copepod nauplii (Arthur, 1956). The mode falls between 75 and 80μ. The volume of a nauplius 80μ wide is approximately 4.0×10^{-4} mm^3 and the dry weight of an animal of this size is 1.2×10^{-7}g if the animal is 70 percent water. The caloric content of the copepods *Calanus helgolandicus* and *Tigriopus cal-*

TABLE 2

CHANGING INCORPORATION EFFICIENCY WITH YOLK UTILIZATION IN SARDINE EMBRYOS (14° C)

1 Elapsed hours from spawning	2 Time intervals	3 Total calories consumed per time interval	4 Catabolic calories per time interval	5 Incorporated calories 3–4	6 Incorporation efficiency
42	42	.040	.0063	.0337	84
71	29	.100	.0096	.0904	90
80	9	.030	.0040	.0260	87
100	20	.045	.0088	.0362	80
120	20	.037	.0088	.0282	76
140	20	.027	.0088	.0182	67
160	20	.016	.0088	.0072	45

$$\text{Per cent incorporation efficiency} = 100 \times \frac{\text{Incorporated calories}}{\text{Total calories consumed}}$$

ifornicus is shown in Table 3 (mean caloric value = 5100 cal/g dry weight).

TABLE 3

CALORIC CONTENT OF TWO SPECIES OF COPEPOD, *TIGRIOPUS CALIFORNICUS* AND *CALANUS HELGOLANDICUS*

(Measurements made by Drs. B. L. Slobodkin and S. Richman, University of Michigan)

T. californicus, 0.9–1.1 mm	
Dry wt. (mg)	cal/g dry wt.
13.66	5250
14.63	5268
15.00	5374
C. helgolandicus, stage V and adults + 6.5% other planktonic material	
25.26	5125
20.10	5103
24.95	4917
24.05	4910

Average of 7 determinations: 5135 cal/g dry wt.

Therefore at 14°C, to maintain catabolism, 0.7 copepod nauplius/hr must be ingested and digested by the newly feeding larva. To continue energy uptake equivalent to average yolk absorption, 2.8 copepod nauplii/hr are required. Per cent digestion is very high in fishes, usually over 80 per cent (Winberg, 1961). With a correction for per cent digestion these values can be adjusted to 0.9 nauplius/hr for catabolism only and 3.5 for total metabolism (which includes growth).

The effect of temperature on yolk absorption was determined and is plotted in Figure 4; a regression line is fitted to the data. The Q_{10} for this process is 4 for the environmental temperature interval from 15 to 21°C. Therefore, for each 5°C rise in temperature the rate of yolk utilization is doubled and will be reflected in the food requirement by doubling the number of food organisms required when the larva starts feeding.

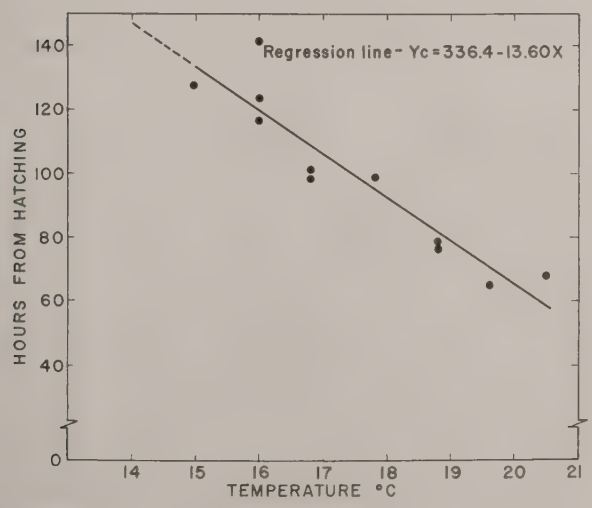

FIGURE 4. The effect of temperature on yolk absorption ($Q_{10}=4$).

VARIATIONS IN THE YOLK SUPPLY

Basing metabolic measurements on an average larva avoids the obvious fact that all eggs are not alike and all do not have the same potential. For example, there are small but significant differences in the amount of yolk available to the newly fertilized sardine egg, and in the chemistry and caloric value of the yolk. Yolk volumes may vary from 0.5 mm^3 to 0.6 mm^3 and the per cent dry weight of the yolk may span in one standard deviation 7.4 to 10.2 per cent. Although the nitrogen content (and therefore the protein) of the yolk is very constant, variations in the fat can be great. Phospholipids varied from 10.3–17.5 per cent in six individual determinations, total fat from 11.0-14.4 per cent in 11 determinations and caloric value for yolk from 5007 to 5598 cal/g in 9 determinations. An egg having a yolk volume of 0.5 mm^3, could provide as little as 0.185 cal to the growing embryo which may be compared with the 0.3 cal available in an egg of average volume, dry weight and caloric value.

Figure 6 illustrates the variation in growth of sardine larvae kept at 17°C in the laboratory. All larvae hatch out at approximately the same length, but as time progresses and yolk reserves are depleted, the divergence in length becomes great. The consequences of variations in the yolk supply of individual embryos is not known as yet, but it seems safe to conclude that this may contribute to the generally observed wide differences in growth of sardine larvae at all temperatures.

Growth curves of yolk sac larvae at different temperatures (Fig. 3) show that after reaching a maximum length the sardine larva begins to shrink. Shrinking is a result of starvation since weight loss is a concomitant feature of this phenomenon and it can be shown that there is a sharp decrease in the quantity of structural proteins associated with this shrinking. The change in amount of cold trichloroacetic acid precipitable proteins with time and development is plotted in Figure 7. The curve shows the build-up of the somatic proteins and the subsequent decrease in these proteins with starvation; a horizontal bar indicates the time span over which the articulated jaw may complete its development. It is prior to this period that a metabolic deficit begins, and this once again illustrates the delicate balance between metabolic needs and the onset of feeding.

As far as growth of the post yolk sac larva is concerned no information is as yet available and until we are able to rear them in the laboratory, energy and food requirements will not be precisely known.

SWIMMING

The most important drain on the energy resource of the sardine larva is its swimming activity. Lasker and Theilacker (1962) have shown that swimming can increase the oxygen consumption of a sardine larva as much as 3.5 times its basal uptake but the average increase in Q_{O2} ($\mu l\ O_2$/larva/hr) is 2 × the basal rate (Table 4). Dr. Schumann discusses in this symposium

TABLE 4

AVERAGE INCREASE IN OXYGEN CONSUMPTION BETWEEN INACTIVE AND ACTIVE EGGS AND LARVAE (14° C)

Q_{O_2} = µl O_2/egg or larvae/hour (Lasker and Theilacker, 1962)

	Number	Q_{O_2} inactive	Number	Q_{O_2} active	Increase O_2 consumption with activity
Eggs	8	0.0321	10	0.0714	2.2×
Larvae	7	0.0533	17	0.1072	2.0×

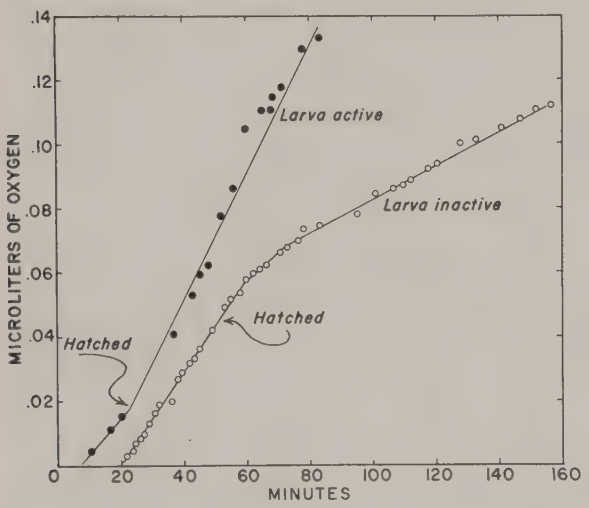

FIGURE 5. Effect of activity on oxygen consumption of sardine larvae. (Lasker and Theilacker, 1962).

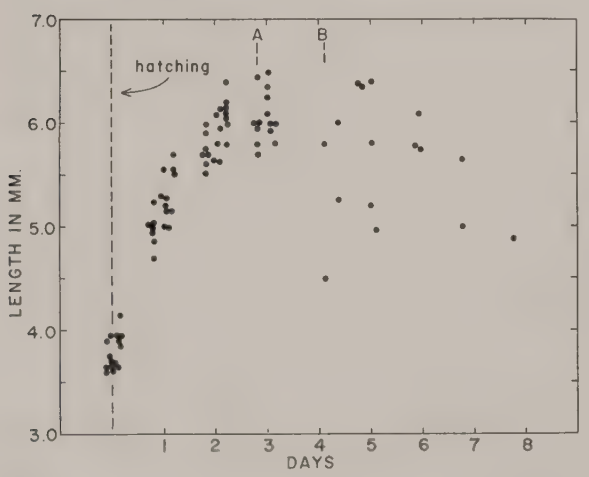

FIGURE 6. Variation in length of developing sardine larvae at 17° C. "A" indicates the time when development of a moveable jaw and eye pigmentation is completed; "B" is the time when the yolk is completely consumed.

the behavior of sardine larvae after yolk absorption and during the onset of their feeding. He has found that swimming and feeding alternate with periods of

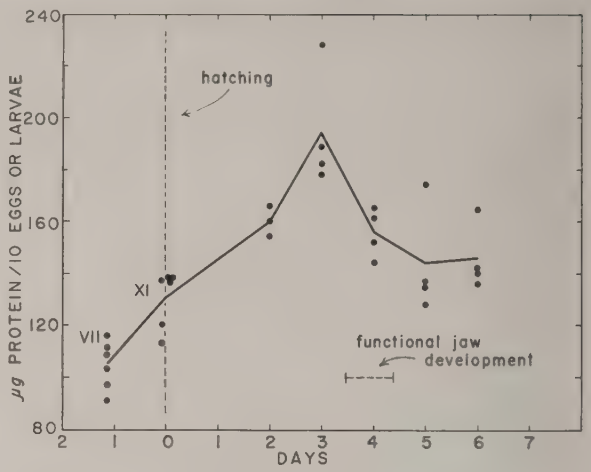

FIGURE 7. The quantitative change of somatic protein with time of development (16° C). Protein was precipitated with cold trichloroacetic acid.

rest, so that on the average a larva spends about 40% of its time swimming and 60% resting. As the larva grows, swimming time gradually increases and is continuous when the animal reaches about 9 mm in length. Figure 5 illustrates the effect of swimming activity on the energy requirement of the larva. The fact that the newly-feeding animal has alternate periods of rest and swimming allows the larva to conserve its energy at a critical time in its life cycle. Were swimming to be continuous at this time and no food found, the two-fold increase in its food requirement would further aggravate the energy deficit it is already experiencing.

OSMOREGULATION

The sardine larva is hypotonic to sea water and thus must osmoregulate. Figure 8 presents the osmolar concentrations of sardine embryos and larvae compared with adult sera and plasma (sea water M = 0.56). The surface membranes are permeable to the

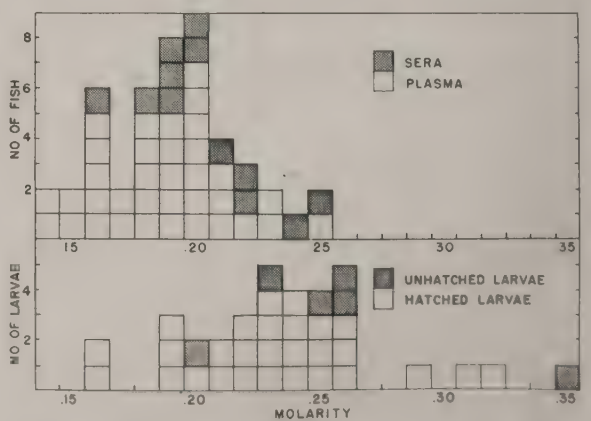

FIGURE 8. Osmolarities of sardine larval yolk and adult sardine sera and plasma.

environment since a loss of salts can be demonstrated after placing the animal in fresh water. Electron micrographs show a typical naked epithelium exposed to sea water. To maintain the hypotonic internal concentration a steady flow of salts must be excreted and water conserved (presumably by the epithelium). No significantly different oxygen uptake was found in larvae at different salinities and our conclusion was that the energy requirement for this physiological function was negligible (Lasker and Theilacker, 1962).

TEMPERATURE

Incubation time, development of a functional jaw and fully pigmented eyes and yolk utilization (Fig. 4) all have a Q_{10} of 4 over the temperature range of 14 to 21°C (Lasker, 1964). At temperatures below 13° C sardine eggs hatch and the larvae develop to some extent, but there is no formation of a jaw and the eyes fail to pigment, therefore 13°C must be considered the lower limit for survival of sardine larvae.

The relative rates of development given in Table 5 indicate that at the lower temperature range, 15°–13° C, sardine larvae spend respectively 2 and 3 times as long in the larval stage as they do at 21°C, but differences in developmental rate at higher environmental temperatures are slight because the time-temperature curve approaches an asymptote. For example development is only 1.2 times longer at 19°C than at 21°C.

TABLE 5

COMPARATIVE RATES OF EGG INCUBATION AND LARVAL JAW DEVELOPMENT—EYE PIGMENTATION AT DIFFERENT TEMPERATURES. RATE AT 21° = 1

(Lasker, 1964)

Temp.	Incubation Time	Eye Pigmentation and Jaw Development
11	4.12	----
12	3.38	----
13	2.74	2.77
14	2.31	2.33
15	2.00	2.02
16	1.77	1.76
17	1.58	1.54
18	1.42	1.37
19	1.27	1.22
20	1.16	1.11
21	1.00	1.00

The Northern Anchovy (*Engraulis mordax*) was also studied with respect to temperature and presents an interesting comparison to the sardine. The anchovy's larval development is normal at 11 and 12° C and at these lower temperatures the anchovy hatches about a day earlier than the sardine. However, at higher temperatures the difference in rates between the two species diminishes although the anchovy always hatches and develops earlier. This is illustrated in Figure 9 and shows incubation time curves with temperature obtained for both species.

It is of interest to note that the lower temperature thresholds for both sardine (13°C) and anchovy

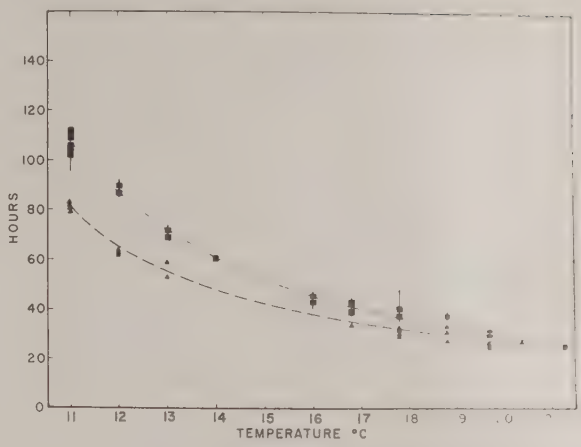

FIGURE 9. Observed incubation times for Pacific sardine and northern anchovy eggs (from stage IV). For the sardine the vertical lines indicate the range at each temperature and the bars the standard deviations around the mean; Δ = anchovy individual.

(11°C) were determined and the effect of temperature on incubation time were deduced from field collections by Ahlstrom (1943, 1956). These have largely been borne out by laboratory results. A comparison of incubation times with temperature obtained by the two methods is given in Table 6.

TABLE 6

INCUBATION TIMES OF PACFIC SARDINE EGGS AT DIFFERENT TEMPERATURES. LABORATORY STUDIES COMPARED WITH FIELD STUDIES

(Lasker, 1964)

Temp. °C	Incubation time in hours* (this study)	Incubation time in hours (Ahlstrom, 1954)	Percent difference†
11	140	114	18.5
12	115	100	[illegible]
13	93.0	88	[illegible]
14	78.5	77	1.9
15	68.1	68	0 [illegible]
16	60.2	60	[illegible]
17	53.7	53	1 [illegible]
18	48.4	46	5.0
19	43.2	41	5.1
20	39.3	36	8.4
21	34.0	31	8.8

* Corrected for time from spawning to stage IV based on field observations by Miller (1952).
† Percent difference is calculated by dividing the difference in hours at a temperature with the time found experimentally (× 100).

DISCUSSION

In 1926, Hjort, in discussing the concept of the "critical period" suggested "that those individuals which at the very moment of their being hatched did not succeed in finding the very special food they wanted would die from hunger. That in other words the origin of a rich year-class would require the contemporary hatching of the eggs and the development of the special sort of plants or nauplii which the newly hatched larvae needed for its nourishment." As this presentation has shown, the sardine larva

seems to fit this pattern in most of its details. Toward the end of yolk absorption and before feeding, the larva is on an energy deficit. This becomes particularly acute when the yolk is completely gone. The timing of development and the metabolic deficit are in delicate balance, and depending on the temperature, a day, or perhaps a few hours in the life of the larva will decide whether it will live or die. Because tissue resorption inevitably ensues, a sardine larva must encounter a particle of food soon after its mouth is formed if it is to have enough energy for succeeding food excursions. It also seems that this encounter may be a chance affair because the larva has not yet fully developed its vision (Schwassmann, this symposium) for accurate hunting.

A true "critical period" for a Pacific sardine larva could be the result of the lack of copepod nauplii or other suitable food organisms of the proper size and in sufficient density to ensure contact the first or second time the sardine larva hunts for food. Dr. Schumann discusses the implication of larval behavioral aspects in relation to feeding elsewhere in this symposium.

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MAINTENANCE OF EUPHAUSIID SHRIMPS IN THE LABORATORY

BY REUBEN LASKER AND GAIL H. THEILACKER

Made in United States of America
Reprinted from LIMNOLOGY AND OCEANOGRAPHY
Vol. 10, No. 2, April 1965
pp. 287–288

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Maintenance of Euphausiid Shrimps in the Laboratory

Euphausiid shrimps are of particular interest to marine scientists because they comprise a major portion of the planktonic biomass in some oceanic areas (Hardy and Gunther 1935); they are indicators of oceanic water masses (Brinton 1962); they are part of, and migrate with, deep scattering layers (Moore 1952); they are important indicators of radioactive contamination of the ocean (Osterberg et al. 1964); and they are important links in the food web of the sea as food for fishes (Merkel 1957) and whales (Hardy and Gunther 1935).

Experimental studies on euphausiids have been hindered by the fact that they have been difficult to keep alive in the laboratory. Baker (1963) reported that he was able to hold euphausiid shrimps alive on board ship from less than one to a maximum of only 15 days. Lasker (1964) in a study of molting frequency of *Euphausia pacifica* kept this species alive in the laboratory for as long as 50 days on a diet of the unicellular green algae *Platymonas subcordiformis* and *Dunaliella primolecta*. However, mortality continued throughout his experiments.

An improved, and now routine, method for the maintenance of adult euphausiid shrimps (between 2.4 and 11.5 mg dry weight) in the laboratory has now been developed using *Artemia salina* nauplii as food (Boyd and Johnson 1963). Once the euphausiids have been established in laboratory containers for a few days there is virtually no mortality using this technique.

Euphausiids are caught with a 1-m mouth diameter plankton net having a quart jar (about 1 liter) as the cod end. Our tows are made off San Diego at a depth of about 250 to 300 m and never exceed 15 min duration at depth, but the slow return to the surface takes approximately an additional 10 min. On board ship the whole plankton catch is emptied into a yellow polyethylene bucket which facilitates sorting because of the ease with which euphausiids can be seen. A dip net fashioned from a length of stainless steel wire with coarse netting stretched across a loop of about 9 cm diameter and the rest of the wire serving as a handle is used to separate the euphausiids from the rest of the plankton.

The euphausiids are transferred to another bucket of seawater previously chilled in the ship's refrigerator to about 10C. No more than 5 animals per liter are carried in these buckets.

Although the travel time between the collection at sea and the laboratory is between 3 and 4 hr, little or no mortality is evident. White, translucent, polystyrene containers of 1-liter capacity are filled with seawater and a single euphausiid placed into each container. The greatest mortality is experienced in the first two days after capture, presumably because of handling. All subsequent handling is done by drawing each animal into a wide bore (6 mm I.D.) pipette and transferring it with a small quantity of water. Each euphausiid shrimp is supplied with several thousand newly hatched *Artemia* nauplii and the containers are covered with black polyethylene sheeting. The darkness insures an even distribution of the nauplii which makes them more available to the filter-feeding euphausiid.

Single *E. pacifica* or *E. eximia* filtered out and ingested as many as 70 to 95 nauplii per day in experiments where only 100 nauplii were offered. The euphausiid's intermolt period decreased to 3 or 4 days instead of the average of 5 days experienced with euphausiids feeding on algae (Lasker 1964). The seawater was changed at least twice a week. Used polystyrene containers were regularly washed with a jet of seawater at each change and with a jet of tap water at least once a month. Temperature was controlled by permitting the plastic containers to sit in running seawater on a water table which insured a narrow range of temperature (16.4C to 14.8C for March–May 1964).

These simple procedures insure us a steady supply of euphausiids for our work on molting and experimental feeding and have successfully maintained three species thus far: *E. pacifica*, *E. eximia*, and *Nema-*

toscelis difficilis. It may also be applicable to other species.

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Reprinted from TRANSACTIONS OF THE AMERICAN FISHERIES SOCIETY
Vol. 94, No. 4, October 1965
pp. 409–412

The Effect of Minimum Temperature on the Survival of Larval Atlantic Menhaden, *Brevoortia tyrannus*

INTRODUCTION

Experiments were performed at Beaufort, North Carolina, from January to April 1964, to ascertain the effect of low temperatures on survival of Atlantic menhaden larvae. Field studies by the Bureau of Commercial Fisheries in Delaware and North Carolina showed that larval menhaden were present in collections from October to May and abundant from December through March. June and Chamberlin (1959) reported that larvae occurred in abundance outside the river mouths after hatching at sea, and entered the estuaries during winter and spring months. However, larvae were absent from the plankton tows when water temperatures went below 3.0 C. Thus, entry of menhaden larvae into the estuary apparently can be affected by water temperature. Kinne (1963) considered temperature a primary factor governing survival and distribution of marine animals.

COLLECTIONS OF EXPERIMENTAL STOCK

Larval menhaden, 17 to 34 mm total length, were collected in Beaufort Harbor with a 1-m plankton net of 0.9-mm braided nylon mesh attached to a Chesapeake Bay-type crab float, 120 by 90 by 40 cm, lined with plastic screen. The cod end of the net was connected by a stainless-steel clamp to an 8-cm pipe that projected from one end of the float. The net, tied to a bridge near the center of the channel, was fished at night during flood tide. The tidal current swept several species of larval fish through the net and into the float. Once the current started to slack, few larvae entered the net.

The larvae were attracted to the surface of the crab float with a 6-v marine lantern, then dipped into 10-liter plastic buckets. Larvae were transported to the laboratory within 20 minutes and since exposure to air causes death, they were kept in water at all times during the transfer. Little sloshing was permitted in the buckets as this action also may cause death. The menhaden were separated from other fishes in the laboratory.

EQUIPMENT AND PROCEDURE

Three tanks, painted with nontoxic black Inertol[1], held larvae prior to their transfer to an acclimation tank. A standpipe maintained the water depth at 20 cm in each of two smaller tanks, 60 by 130 cm and suitable for holding 300 larvae. Water depth was maintained by a standpipe at 25 cm in a larger tank, 80 by 120 cm, suitable for holding 400 larvae.

Salt water from Beaufort Harbor, pumped through a filter of glass wool and marble chips to remove silt and organisms, flowed continuously into the holding tanks and kept the water temperature in these tanks approximately the same as in the harbor.

The acclimation tank, a converted chest-type freezer lined with Fiberglas[1] and painted with Inertol, was suitable for holding 150 larvae. It was divided into two sections, each measuring 60 by 60 cm, with water depth maintained at 23 cm. The water temperature was held constant by a mercury regulator. The regulator controlled an electronic relay that either activated a 500-w immersion heater or a solenoid valve that controlled the coolant in coils embedded in the walls of the freezer.

Three separate Fiberglas chambers, each measuring 80 by 80 cm and filled with water to a height of 28 cm, were used to test larvae. Temperature was controlled as in the acclimation tank except that the cooling coils were exposed directly to the water in each chamber. A wooden frame in each chamber supported four polyethylene 10-liter buckets containing larvae. These buckets were filled with 8 liters of water and submerged until the water level in the buckets was the same as the chamber. Temperature of the water in each chamber was recorded continuously with a thermograph.

Compressed air was used to oxygenate and stir the water in the acclimation tank, the Fiberglas chambers, and the polyethylene buckets. Dissolved oxygen, checked periodically in all containers, ranged from 80% to 95% saturation. Once each day newly hatched brine shrimp were fed to all larvae.

Larvae were subjected to test temperatures they might encounter in the estuary to determine the relation between survival time and temperature. Larvae were acclimated for 12 hours or longer at temperatures of 7.0, 10.0, 12.5, 15.0, and 20.0 C. For each test, 10 larvae were placed in each of four polyethylene buckets at the acclimation temperature, or a total of 40 larvae. The buckets were immersed in the Fiberglas chambers held at preset temperatures. The water in the buckets reached temperature equilibrium within 2 to 3 hours. Each test was continued until 50%, or more, of the larvae died. A median value, expressing 50% survival time, was calculated from the combined four replications. Each series of tests included temperatures between 0.0 and 6.0 C by half-degree intervals. However, in the 10.0 C acclimation series, a test at −1.0 C also was included, and in the 15.0 C series, 7.0 and 8.0 C tests were made. A control bucket with 10 larvae was aerated and kept at room temperature for each test.

In all tests, salinities were measured by a conductivity bridge and adjusted to 24 ± 1‰

[1] The Bureau of Commercial Fisheries neither recommends nor disapproves the products referred to in this paper.

TABLE 1.—*Number of hours to 50% mortality of menhaden larvae exposed to different temperatures*

Acclimation temperature Celsius	Test temperature C							
	−1.0	0.0	0.5	1.0	1.5	2.0	2.5	3.0
7.0	–	8.5	11.5	13.0	33.5	38.5	40.5	37.5
10.0	4.4	5.2	9.0	5.3	16.7	20.4	23.0	33.2
12.5	–	4.2	7.0	9.6	13.4	17.9	17.7	36.0
15.0	–	3.4	6.4	6.0	4.5	14.5	10.0	23.4
20.0	–	2.1	–	–	–	3.2	–	–

Acclimation temperature Celsius	Test temperature C							
	3.5	4.0	4.5	5.0	5.5	6.0	7.0	8.0
7.0	77.0	96.0	>137.5	>137.5	–	–	–	–
10.0	46.0	26.8	132.7	130.0	>144.0	>144.0	–	–
12.5	39.2	45.0	60.0	132.0	216.0	>216.0	–	–
15.0	18.9	45.7	36.4	140.0	140.0	70.0	82.8	>169.0
20.0	–	11.2	–	–	–	–	–	–

by the addition of distilled water. Evaporation was reduced by a Plexiglas[1] cover over each bucket.

Overhead, pink, 40-w fluorescent tubes gave continuous lighting. Perlmutter and White (1962) recommended pink lights for fish hatcheries after concluding that the strong emission of visible blue light by cool–white fluorescent tubes caused a high mortality among brook trout eggs.

In those experiments where all larvae died, the lengths of larvae were examined to determine if there was any relation between the size of larvae and the length of time the larvae survived. Experiments were run so that observations could be made prior to and following the time of 50% mortality. Larvae were considered dead when no body movement occurred or could be induced. If larvae revived when removed from the water, they were returned to their test bucket.

RESULTS AND DISCUSSION

Behavior of larvae in test buckets followed a definite pattern. As they became chilled they lost equilibrium, floated and twitched erratically, and finally settled on the bottom. A response could be initiated by touching these larvae with a probe. Larvae that apparently were dead could be removed from the water and warmed; if still alive, heart pulsations or muscle reflexes occurred.

Table 1 lists the number of hours that larvae survived before a 50% mortality occurred. Generally, larvae acclimated at cooler temperatures survived longer at a given test temperature than those acclimated at warmer temperatures. Due to equipment failure and subsequent repair, some of the larvae from the 15.0 C acclimation series were in holding and acclimation tanks for a month or longer. Ordinarily, larvae were kept in these tanks for 2 weeks or less. The uneven results in the 15.0 C acclimation series may be due to holding larvae an extended time or possibly are characteristic of larvae acclimated at this temperature. Only three tests could be completed in the 20.0 C acclimation series.

In several cases during equipment failure, the water temperature dropped to near freezing for several hours. Approximately one-third of the larvae that were exposed to this low temperature for less than 3 hours recovered when warmed to room temperature.

Length frequencies of larvae from those experiments in which all larvae died indicated no relation between the size of larvae and survival time.

With few exceptions, larvae acclimated at 7.0 C survived 0.0 to 4.0 C approximately 1.5 to 3.5 times longer than those acclimated at warmer temperatures and the survival time increased with increased test temperature. There was a marked difference in the survival time of larvae acclimated at different temperatures and tested at 4.5 C. Larvae acclimated at 7.0 and 10.0 C survived over twice as long as those acclimated at 12.5 or 15.0 C. Larvae survived equally well at 5.0 C for all acclimation temperatures. Those tested at 5.5 C and above survived for approximately 6 days or more, except for larvae acclimated at 15.0 C. Larvae from the 15.0 C series showed poor

survival at 6.0 and 7.0 C, possibly due to holding larvae more than a month. Larvae in the control buckets did not die during any experiment. On the basis of these data, it appears that acclimation temperature is more important to the survival of larvae at test temperatures less than 5.0 C than it is at 5.0 C and above.

The experiments conducted in the laboratory partially explain the absence of menhaden larvae in plankton collections taken when water temperatures were below 3.0 C. Whether the larvae were killed or avoided the cold water in the estuaries has not been determined.

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POSTLARVAL BROWN SHRIMP ABUNDANCE AND FISHING SUCCESS

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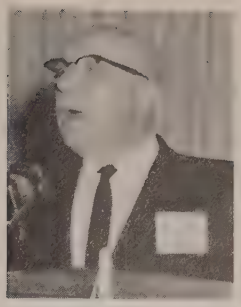
Abstract

A 5-foot, hand-drawn beam trawl operated semi-weekly over a five-year period at one station in the Galveston Entrance has provided indices of abundance for postlarval brown shrimp which correlate well with catch indices obtained for juveniles and adults. Laboratory experiments suggest that survival of yearly arriving postlarvae may be adversely affected by low temperatures and salinities.

Proc. Gulf and Caribbean Fish. Inst.,
17th Annual Session, p. 19.

MARICULTURE . . .

Its Recent Development and Its Future



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Presentation was made during the General Session of Winter Meeting of ASAE at Jung Hotel, New Orleans, La., Dec. 1964.

THE story of humanity is a succession of events which follow each other in somewhat logical sequence. In the early stages of the formation of human society, man depended for his existence upon hunting and gathering wild fruits and seeds. As the human race grew older and wiser and as game became scarce in many areas, the era of hunting and seed-gathering came to an end and the era of farming began. This era, which has covered several millennia, progressed relatively slowly, and it is only during the last century, especially the last three of four decades, that it has made rapid progress.

The agricultural era may now be passing through its most successful period, and there is every reason to believe that this period will be of long duration. Nevertheless, certain signs suggest that, regardless of the recent phenomenal developments in agricultural methods, the time is approaching when our land will be unable to produce enough food for mankind. This pessimistic prediction, familiar to all of us, is based on the rapid increase in population and the somewhat less rapid but, nevertheless, consistent decrease in land area used for food production.

Calculations concerning the so-called population explosion show that at present the world has between 2½ to 3 billion inhabitants. This number increases an average of 2 percent per year. If the current rate of increase is maintained, the present population will be doubled by the year 2,000 and it will continue to double every 37 years. This astonishing but, nevertheless, frightening reality is based on the fact that the increase in the world's population follows a geometrical progression.

Because of this circumstance it is indeed clear that we should not delay planning for conservation of the present food-producing sources and for the development of new methods to increase the food production of the world. By developing better strains of plants and animals, by using better fertilizers and more effective methods of controlling enemies of commercially important plants and animals, as well as by converting large arid areas into productive farm lands, we may succeed for several generations in holding our own in producing sufficient food for the people. The question is, How long can we continue to do so, and what can be done to ameliorate the situation? We think that by developing the most promising aspects of mariculture — the science of farming the seas and oceans — we shall be able to increase by a substantial margin the quantity of food available to future generations.

During the last few decades it has become fashionable, in some groups, to maintain that, in reality, the increase in human population and the decrease in land area available for agriculture are not serious problems because, if necessary, we can always go to the oceans for our food. It is reasoned that since the seas and the oceans cover the greater portion of our globe, they contain boundless wealth, and, consequently, can easily become the chief food suppliers for humanity. This fallacy persists in many quarters even though marine biologists and oceanographers openly contradict it by offering reliable evidence to show that populations of oceanic fishes are not so great that they cannot be quickly and drastically diminished by man's fishing efforts. In fact, anyone willing to study the history and statistics of our major fisheries will have little difficulty in ascertaining that intense fishing with modern equipment can in most instances rapidly reduce a large fishery population to a relatively low level.

It is true that, because of rapid improvements in fishing methods, large catches of fish can be made for short periods in many oceanic areas, especially where almost no commercial fishing was done previously. However, the efficiency of fishing methods is increasing so rapidly that even untouched populations may soon be exhausted. We must also remember that the oceanic fishery will always be an expensive undertaking, requiring costly vessels and highly-specialized equipment.

It is not my purpose, however, to discuss in this article details of the future of oceanic fin-fisheries. I merely want to emphasize the dangers of overoptimism in thinking that the oceans can forever provide humanity with the food that is needed. Such miracles perhaps will be achieved in the remote future through new knowledge which, unfortunately, is unavailable to us now. At present, however, we have little hope of increasing production of oceanic fishes, such as tuna, by employing hatchery techniques or similar methods.

After finding that the resources of our oceans are not inexhaustible and that, at present, we can do little to increase them, the question naturally arises, Can anything be done to obtain more food from the oceans? The answer is an emphatic, Yes. However, to achieve this we should concentrate, for the time being, on utilization of numerous estuaries, such as harbors, bays, and sounds. Furthermore, instead of thinking mainly in terms of producing oceanic fish, we should direct our efforts to raising other forms, commencing with algae, and extending them to production of commercially important mollusks and crustaceans. Culturing certain species of fish in salt water ponds or other artificial enclosures should also be considered an important part of mariculture. However, these activities will not be discussed in this article.

Mariculture, as already mentioned, is farming of the sea — in other words, a science related to agriculture, farming of the land. Mariculture is not a new conception. More than two thousand years ago the Romans, the Chinese, and probably other peoples attempted to cultivate sea forms by growing them

This article is reprinted from AGRICULTURAL ENGINEERING (vol. 46, no. 2, pp. 73, 93-97, February 1965), the Journal of the American Society of Agricultural Engineers, St. Joseph, Michigan

under more or less controlled conditions. The first reliable record of Roman oyster culture offered by Pliny tells us that Sergius Orata established some type of oyster farming in Baiae near Naples one century B.C. He also planted oysters in Lake Lucrinus to improve their flavor. Later, the Romans imported English oysters for home consumption. They regarded these mollusks highly and, as a matter of fact, Sallust said "Poor Britons — there is some good in them after all — they produce an oyster."

Designs appearing on vases show that the Romans cultivated oysters by suspending bunches of them in loosely twisted ropes, a method still used in the Bay of Tarranto and the Gulf of Spezia. Thus, the beginning of oyster cultivation can be traced back at least two thousand years and judging by the contents of many prehistoric kitchen middens, it is possible that primitive methods of oyster cultivation, such as gathering them and storing them in small, isolated, salt water ponds for later use, may have been practiced much earlier. It is undeniable that, because kitchen middens containing oyster shells are found in many coastal areas of the world, the role of oysters in the diet of early peoples was extremely important.

Because of the short time allotted to this discussion it is impossible to consider, even briefly, all the aquatic forms that can be grown under controlled or semi-controlled conditions. These forms are numerous, extending, as already mentioned, from microscopic algae to fishes, and include representatives of almost every phylum living in sea water. I shall limit my discussion to three major groups whose cultivation should eventually constitute important fields of mariculture. These are algae, mollusks, and crustaceans.

Algae

Marine algae are aquatic plants ranging in size from gigantic forms over 100 ft long to minute, unicellular species which can be seen only under a microscope. Many species of large marine algae have been used as food for centuries. In Japan and China, for example, many seaweeds are eaten; while in Europe dried algae is used as cattle feed and fertilizer. In this country algae commonly called Irish moss is harvested on a commercial scale along the New England coast. Seaweeds, as is well-known, have been used in China as a goiter preventive. Production of large seaweeds can be increased considerably by growing them in enclosed or semi-enclosed natural or artificial basins which can be properly fertilized to increase their productivity. However, culturing of microscopic, unicellular forms should probably be the first to be tried on a large scale.

Scientists of different disciplines have emphasized that the world needs additional sources of high protein food. If culturing of algae can contribute to the satisfaction of this demand, a great deal will be done toward solving the problem of feeding people in countries such as Japan, India, and Israel, where fertile land is rather limited and insufficient to produce enough food, and in densely populated areas where land surface is at a premium. This, of course, does not mean that our present knowledge is broad enough to solve all the difficulties that may be encountered. Many problems remain unsolved, not because they are too difficult but because, as yet, relatively few people have worked on the development of methods for large-scale culture of algae. However, since scientists solved the problems of space navigation they can surely solve the problems of mass growing of algae so that such an enterprise will become practical.

We also think that to succeed the problem should not be left entirely to biologists but solved by combining their efforts with those of engineers having experience in agriculture. By combining the talents, experience, and knowledge of these two groups a rapid advance in the technology of mass culture of useful unicellular algae can be accomplished.

What may we achieve by growing marine algae on a large scale? We cannot predict all its future uses, but we can name those of which we are already aware. Algae is used as human food. For example, dried unicellular algae, *Chlorella,* has a flavor not unlike lima beans. In Japan it is used as an ingredient of many dishes and in many foods. Algae can be used as cattle fodder or chicken feed. Some admixture of dried algae to fish food used in hatcheries may be beneficial to fish. In our own work of culturing commercial mollusks, such as oysters and clams, under hatchery conditions, we have grown both larvae and juveniles on dried algae with considerable success. Earlier experiments in which we tried to fatten the oysters by feeding them pulverized, dried algae gave promising results but, unfortunately, these experiments could not be carried to completion because of the advent of the second world war. It is possible that some algae may be sources of commercial antibiotics, vitamins, and sterols.

We are interested in unicellular algae as a possible food source because in some of these forms almost the entire plant is of nutritive value. With few exceptions, only a portion, such as the fruits, seeds, or roots, of plants grown on dry land is food, the rest serving merely mechanical purposes. A second important consideration in favor of growing algae is that in the dry state it often contains over 50 percent protein, much more than is normally found in the parts of higher plants used for food.

At present it is illogical to apply a conventional cost analysis to the production of materials obtained from algae because we know too little about the entire matter. A great deal should depend upon finding, isolating, and culturing species of algae that appear promising for particular purposes. So far, most experiments on the large-scale culture of single-celled algae have been conducted with several species of the genus *Chlorella.* We know, however, that this is one of the least desirable forms because of its morphological characteristics, chiefly its heavy cell walls. In our experiments in shellfish hatcheries, where we fed larval and adult mollusks different types of algae, *Chlorella,* commonly called an algal "weed," proved the least desirable species. Nevertheless, it has been selected for experimental purposes by most investigators because of its hardiness and the ability to withstand sharp changes of environmental conditions. Because of this consideration *Chlorella,* or an equally hardy species, may be used in initial efforts to develop methods of mass algal culture; but later it should be replaced by more desirable types, which will surely be found among the thousands of species of microscopic marine algae.

As already mentioned, the possibility of producing, in large quantities, a plant food of high protein content, such as some species of unicellular algae, is important in our plans for the future. Unfortunately, I cannot give even an approximate description of methods that will be used for this purpose a century from now. I may mention, nevertheless, some approaches used in this country and abroad, especially in Japan where experiments in growing *Chlorella* for food and other purposes are conducted, on a comparatively large scale, under the direction of Professor Tamiya of Tokyo. In Japan powdered dried *Chlorella* is already added to various foods, including noodles, rice crackers, jelly beans, soy beans, and even soups. According to Dr. Tamiya green-colored vanilla ice cream, containing *Chlorella* powder, is relished by many people.

Mass algal cultures can be grown by a variety of methods. Basically, there are two types. The first consists of growing algae in a closed system. The cells are grown in containers with transparent upper surfaces or in long tubes made of transparent polyethylene plastic through which sunlight can penetrate. This approach has advantages because the introduction and dispersion of carbon dioxide needed for algal growth is relatively easy and the cultures in the closed system are better protected against various types of contamination, includ-

ing algal predators such as protozoans and small crustaceans.

The second approach, the method of open culture, consists of growing algae in large, shallow, open basins. The initial cost of this approach should be considerably lower than that of the closed method. There are disadvantages, however, such as difficulty in maintaining a carbon dioxide concentration high enough to produce the best cell growth; and the ponds may be easily infested by predators. However, because the open method is cheaper and simpler it may be preferred, especially in undeveloped countries.

Preventing contamination of mass algal cultures by undesirable organisms is possible. In our work at Milford we found that, by adding to the mass cultures small quantities of relatively harmless chemicals, which become hydrolized in a short time, we eliminated crustaceans such as small copepods or *Artemia.* The Japanese routinely use chemicals in their outdoor cultures to control protozoans and rotifers.

Theoretically, the algal growing basins can be easily excavated by bulldozers. Their approximate depth should be about 3 ft. To prevent seepage of water from the ponds the bottoms can be covered with a layer or layers of thin plastic which are, in turn, covered by several inches of soil. In parts of the world where sunlight is too intense the ponds may be shaded by cheap material, such as cheesecloth. Mechanical agitation of the water and the addition of carbon dioxide and specifically formulated fertilizers are prerequisites for success.

When cultures are dense enough they can be harvested by several methods, including centrifuging. At present this may be expensive, but it must be remembered that the cost of centrifuging will be reduced proportionately to the density of cultures. Use of a series of centrifuges, some of moderate and others of high speeds, may be advantageous. Harvesting may be made less expensive by using gravity sedimentation prior to centrifuging.

Freeze drying is another method of harvesting algae. It has been tried in Japan and found satisfactory. An auxiliary method is spray drying. It consists of using the algal cakes obtained by centrifuging to make a thick suspension of cells in water and introducing this suspension in an "atomizer" at about 100 C. The final product is a dark green powder.

To conclude the discussion of the possibilities of artificial cultivation of microscopic algae we may say that this branch of mariculture, while still in its infancy, may eventually become an important source of food for people and farm animals. We realize that many difficulties will be encountered before algae-producing "farms" or "factories" are so functional that they can be operated at a profit. Processes of extracting from algae products such as proteins and vitamins may at present be too costly to be practical. We must remember, nevertheless, that until now most studies of mass production of algae have been with *Chlorella,* probably one of the least desirable genera to be used for this purpose. We must, therefore, experiment with many other species of algae, selecting those that seem most promising for producing compounds of greatest practical importance. Finally, we must attempt to develop hybrid strains of the best species, as done in agriculture and cattle breeding. Parallel to studies of the biological problems we should develop the technology of algal production by combining, for a successful solution of this important endeavor, the efforts of biologists and engineers.

Mollusks

Molluscans are the second group suitable for mariculture. The fact that representatives of this group are admirably adapted to farming of the sea explains why the people of past eras attempted the cultivation of oysters, clams, mussels, and perhaps some snail-like forms. My own interest in mariculture concerns chiefly this group, principally oysters and clams. During the last few years I have also become interested in the possibilities of culturing marine snails, such as abalone, of which several species are found along our Pacific coast, as well as on the coasts of Japan, China, the Philippine Islands, and the Malayan archipelago. In Europe abalones are found in the English Channel and along the west coast of France. These mollusks are used for food almost everywhere they occur, and in California abalone is a common dish.

During the past 20 years great progress has been made in developing methods of cultivation of commercial mollusks. These studies, conducted principally at the U. S. Bureau of Commercial Fisheries Laboratory at Milford, Conn., have advanced our knowledge to the extent that several commercial hatcheries on the Atlantic coast are now attempting to culture clams and oysters. In Japan research along the same lines has been conducted by Dr. Imai and his group, while Dr. Takashi Ino has been successful in propagating abalones.

Before describing hatchery methods and what they may do for the future of shellfisheries, I would like to mention that shellfish farming is already an important industry in many countries, especially the United States, Japan, France, Holland, and Italy. In this country we grow oysters in almost every state possessing a seashore area. On the Atlantic and Gulf of Mexico coasts the native American oyster, *Crassostrea virginica,* grows under conditions ranging from complete lack of cultivation in some southern states to the high type of oyster farming practiced on the private beds of New York, New England, and several other Atlantic areas. On the Pacific coast a closely related form, *Crassostrea gigas,* imported as seed oysters each year from Japan, is grown in Washington, California and, to a limited extent, in Oregon. Our native Pacific oyster, *Ostrea lurida,* or Olympia oyster, is still found in small numbers and is sold at relatively high prices.

In 1949 we introduced from Europe another species, *Ostrea edulis,* the edible oyster of Europe which, since then, has become established in small numbers in the waters of Maine. Recently this species was introduced into several small bays and harbors of the Pacific coast where, especially in California, it does remarkably well.

In Japan, France, and Holland mussel culture is an important commercial practice, and edible mussels, *Mytilus edulis,* are grown in large numbers. Clam culture prospers in parts of Japan. In all the above cases, however, the industries are based on natural set, i.e., the naturally occurring new generation of mollusks. Frequently these sets fail, leaving the industries without reserves for future harvests. The need for shellfish hatcheries is obvious for the above reason and because many natural beds that supplied sets are rapidly disappearing due to the encroachment of civilization over inshore and estuarine areas. Industrial and domestic pollution also contributes to the disappearance of oyster and clam beds suitable for natural propagation. It seems apparent, therefore, that to continue having clams and oysters available for food we must depend, to a large extent, upon shellfish hatcheries. Not only will hatcheries provide a more dependable supply of shellfish than naturally occurring sets, but they will permit use of many areas for shellfish culture even when the local conditions become unfavorable for natural propagation of these mollusks.

Several additional reasons favor artificial propagation. One is that we may improve on nature in some respects. For example, rather than depend on new generations of juveniles collected under natural conditions, whose characteristics cannot be controlled because we cannot choose their parents, we can select for breeding purposes certain individuals with desired qualities and rear their offspring in the hatcheries. The qualities we seek in the parents are resistance to diseases, rapid growth,

and the ability to grow in areas that at present are not too favorable for their existence. Another advantage is that hatchery production of young oysters, clams, or mussels can be adjusted to meet the exact requirements of shellfish farmers who specialize in growing seed to marketable size.

Our rapid progress in developing functional methods of rearing young mollusks was due to the discovery made at our Milford laboratory that clams, oysters, and other mollusks can be made to ripen and induced to spawn any time during the year. Because in New England mollusks normally propagate only during the short summer period, the new discovery was of significant help in allowing us to work with eggs and larvae of bivalves regardless of the season. Working on a year-round basis we soon developed several simple but effective methods by which eggs could be hatched and larvae reared successfully even under crowded conditions.

At the same time we developed means for providing good, live food for larval and juvenile mollusks. We also made considerable progress in preparing and storing for future use such foods as dried algae. For example, we successfully raised larvae of the common hardshell clam of the Atlantic coast, *Mercenaria mercenaria,* called "quahog," exclusively on dried algae. Moreover, being able to raise larvae through all stages of development, we learned through experiments a great deal about the ecological requirements of these organisms, including optimum temperatures and salinities at which they should be reared. We also learned a great deal about larval diseases and their prevention and control. Finally, we developed a number of effective methods to control many enemies and competitors of hatchery-grown mollusks.

The above-mentioned achievements permit us to begin experimenting with pilot shellfish hatcheries, although we realize that our knowledge is far from complete and that we can expect many new problems in connection with their operation.

The next logical step, after securing a set of mollusks, is to grow them to marketable size. While this can now be accomplished on improved or natural beds, in the future the majority of mollusks will probably be grown under somewhat artificial conditions, such as being suspended in special trays or being kept in shallow ponds fertilized to produce more abundant plankton. At this stage in mariculture the biologist needs the engineer's help in designing various mechanical devices whereby mollusks may be grown faster and kept in healthier condition.

Oysters are normally replanted several times between the time of setting and marketing. During the replanting process they can be treated with chemicals to protect them against enemies such as sponges and flatworms and competitors, especially barnacles, hydroides, tunicates, and undesirable types of algae. Treatments to accomplish some of these results are already available; others will have to be found.

Protecting mollusks grown directly on the bottom also presents difficult problems because in that condition they are readily attacked by many predators, including starfish, crabs, boring snails (commonly called oyster drills), and even fish. Fortunately, during the past 20 years we have made good progress in developing means of controlling many of these enemies. Some of the methods are mechanical, as simple as a low wire fence around the shellfish bed to exclude crabs and starfish. Other methods depend upon the use of chemicals to control oyster drills and related forms. One of these consists of spreading on the bottom dry sand mixed with chlorinated benzenes in which a small quantity of relatively mild insecticide is dissolved. In general, we now have some extremely effective chemical methods and we are certain that, as is the case in agriculture, mariculture will also depend, to a large extent, upon chemical methods to control enemies of edible mollusks and, no doubt, some other commercially important marine forms.

It must be remembered that in using chemicals we need to be aware of the possibilities of polluting the water and of incorporating in the bodies of commercial or sport species substances undesirable in human food. Consequently, we should exercise extreme caution in this respect. Moreover, methods employing chemicals should be used only with the knowledge and approval of the U.S. Public Health Service and Food and Drug Administration.

We also plan to use in mariculture any biological methods of control that show some promise and are safe. Some work in this field has already been done, and we hope to see additional progress in this direction.

In conclusion, I believe that the future of the shellfisheries industries based on artificial cultivation is extremely promising. However, success may require some time to attain and will be achieved, as in the case of mass culture of algae, only by a combination of the efforts of biologists and engineers.

Crustaceans

Crustaceans are another group that may eventually lend itself to be a mainstay in mariculture. This large group includes lobsters, crabs, and shrimps, as well as many other forms not well-known to the public. The three major groups, however, are familiar to us all and support important fisheries in many parts of the world, including this country, where shrimp fishery is one of the most important aquatic industries.

The artificial rearing of commercially important crustaceans beginning with hatching the eggs and following with growing larval and sometimes post-larval stages, has been attempted by many investigators. Unfortunately, due to difficulties in culturing these forms, the results were somewhat discouraging. However, since these forms are so important commercially, scientists persisted in their efforts and, in some cases, obtained satisfactory results.

Cannibalism and unexplained mortalities, probably due to diseases caused by fungii and bacteria, are the main reasons for failure in early experiments and in some present ones. A lack of knowledge of the food requirements of larvae and the inability to provide them with the proper quality and quantity of food are other important reasons contributing to the poor survival of young crustaceans. Moreover, the fact that few scientists have worked on the development of functional hatchery methods for rearing crustaceans may explain, to some extent, our slow progress in this branch of mariculture.

About 1865 the famous French biologist, Costé, in cooperation with another French scientist, conducted the first successful series of experiments on artificial propagation of lobsters. In 1905 two Americans, Bumpus and Mead, were successful in culturing lobsters in agitated sea water. From then on the techniques of raising lobster larvae showed considerable improvement; and eventually the Federal government and some states established lobster-rearing hatcheries in Connecticut, Massachusetts, Maine, New York, and Rhode Island.

Young lobsters are usually released on reaching the fourth or fifth stage of development when they display a tendency to go to the bottom and hide among the rocks. The basic idea of the operation was not to raise young lobsters in ponds but to release them into the oceans where they would grow to marketable size under natural conditions. Whether these efforts have contributed to an increase in the natural lobster population has not been definitely proved. However, it is important that by using special hatching equipment lobsters can now be hatched in large numbers. Nevertheless, we need to develop better methods because problems of cannibalism, diseases, proper feeding, and, to some extent, predation, remain unsolved. We know that this can be accomplished but realize it will require much time, ingenuity, and persistence to make artificial rearing of lobsters commercially profitable.

Much less has been done in developing methods of rearing edible crabs.

Nevertheless, some success in this respect has been achieved. In the early 40's biologists of the Virginia Fisheries Laboratory grew eggs of the female blue crab to the first swimming stage. Recently, several investigators in this country and abroad managed to grow crab larvae through several swimming stages. Again, as in hatching lobsters, we anticipate numerous difficulties in growing crabs from the egg stage to marketable size in hatcheries and later in artificial enclosures and know that for some time such efforts, even if feasible, will not be commercially profitable. Nevertheless, studies along these lines must be continued because they may lead us to the stage where methods of hatching and rearing crabs will be so simplified and efficient that raising these crustaceans will be a rewarding occupation for small groups of mariculturists or even single families.

Shimps are the third group of marine crustaceans constituting an important fishery. They are extremely numerous now but may eventually be fished out or their populations reduced so that fishing for them will become unprofitable. Moreover, shrimp fishing vessels and gear are rather costly. Because of these considerations it is believed that raising shrimp under semi-controlled conditions in large enclosures may be practical. We know that in India from 350-1000 pounds of shrimps were produced per acre in a cheaply and simply constructed pond during a season of only five months. These figures were quoted by Gopinath at the Indo-Pacific Fisheries Council of F.A.O. held in Tokyo, Japan, in 1955. This, of course, is a tremendous productivity. Since then, much success along similar lines has been achieved by Japanese biologists and mariculturists. Larval shrimps were hatched artificially from eggs and introduced into rice paddies where they grew to marketable size.

In this country studies of the possibilities of growing shrimps in ponds have been made by Dr. Robert Lunz of Bears Bluff Laboratories in South Carolina. Dr. Lunz, who conducted this work for many years, has done much to demonstrate that shrimps can be grown in large quantities in cheaply constructed marsh ponds in South Carolina and probably several other southern states. In the addendum to this article on pond cultivation of shrimps in South Carolina, published in 1958, Dr. Lunz states that on the basis of careful calculations these ponds can be built for $35-50 per acre. However, these figures apply only to special types of country, such as the low marshes of South Carolina. As an example, Dr. Lunz cites the case of a 40-acre shrimp pond in Colleton County, which was constructed for slightly less than $1500 exclusive of land costs. He emphasizes, however, that regardless of the low cost of constructing marsh ponds, their engineering is an important feature.

Dr. Lunz also mentions that the cost of constructing, maintaining, and operating a modern shrimp trawler is so high that a large acreage of marsh ponds could not only be constructed but maintained and operated for several years for the same sum of money. He is convinced that future research and management studies will make pond cultivation of shrimp a profitable venture.

Conclusion

We may summarize our discussion by saying that mariculture, the branch of science that deals with farming of the sea, especially its intertidal and estuarine zones, is still in its infancy. This is true regardless of efforts initiated many centuries ago to cultivate salt water forms such as oysters and clams.

The relative lack of progress in this field may be explained, in part, by the fact that in many areas of the world there was enough good land to provide food for the people and, therefore, it was unnecessary to seek new sources of food supply. Furthermore, the lack of technical conveniences such as rapid transportation, canning and refrigeration, limited distribution of products obtained from the oceans. Finally, we also lacked a knowledge of the physiological and ecological requirements of the marine animals to be cultured, their diseases and prevention of these maladies and, especially, control of predators and competitors.

During the last few decades the world's human population has shown a sharp increase and, because of this, it has become evident that within a few generations utilization of estuarine areas for food production will become a necessity. Moreover, our knowledge of various aspects of mariculture, ranging from physiological requirements of aquatic forms to the methods of their culture, has rapidly increased. As a result of these recent advances, we may look with assurance to the rapid development of various branches of mariculture.

At this time we cannot predict how farming of the seas will be carried on 100 years in the future. We know, nevertheless, that it is possible theoretically to cultivate a variety of salt water forms, ranging from algae to fish, and that a great deal has already been accomplished in some of these fields. Some of these activities — for example, culturing microscopic forms of algae — may at this time appear impractical and not commercially feasible. Perhaps this is true; but nevertheless we must remember that there are over 10,000 species of algae known to exist in sea water, and that we have not worked with even one percent of them. Yet they differ in many respects. Some algae may be extremely important as sources of antibiotics, vitamins, or other rare substances that may prove valuable in human endeavor, including medicine.

Most of all, we must remember that the most important function of algae is to convert inorganic substances to protoplasm which in turn is fed to higher forms beginning with larvae of mollusks and crustaceans and ending with adding it in some form to cattle fodder and human food.

Equally important is the development of technological methods needed to place different branches of mariculture on a realistic, functional basis. Thus, it will be necessary to combine the efforts of biologists and engineers on many projects leading toward the solution of mass production of marine food forms. Some of these projects will consist of designing hatcheries for cultivation of mollusks or crustaceans; others will deal with growing seed crops so that every square foot of the bottom and every cubic inch of water in aquatic basins will be properly utilized. Still others will be concerned with mechanization of harvesting procedures and the technology of preparation of products for the market. Some of us believe that in a comparatively short time the people of this world will show enough intelligence, ingenuity, energy and, especially, interest to solve these problems. • •

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Reprinted from Biological Bulletin, Vol. 129, No. 3, pp. 546–561, December, 1965

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Printed in U. S. A.

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Although the American oyster, *Crassostrea virginica,* is one of the most common invertebrates of our Atlantic and Gulf coasts, some aspects of its propagation are still not too well known. This is true, to a large extent, concerning the accumulation and release of its sexual products during the prespawning and spawning periods and, especially, the fluctuations in the quantity of gametes (or spawn) developed in different years.

The differences in the quantities of spawn accumulated by oysters in different years were considered important by several students of their propagation. For example, Prytherch (1929) and Needler (1931) maintained that intensity of setting of oysters was governed by the quantity of spawn formed prior to the beginning of spawning. In Europe, Cole (1951) and Korringa (1952) agreed that the numbers of larvae released—and these are roughly proportional to the quantity of eggs developed—control the intensity of the spatfall of the European oyster, *Ostrea edulis.* Although these views are not shared by all workers, it may be assumed, nevertheless, that the fluctuations in the annual quantities of spawn formed by oysters should be regarded as important not only in relation to the recruitment of oysters but also the recruitment of other groups, because eggs and larvae of oysters are eaten by many aquatic forms. For example, the young of a large group of pelagic fishes, especially the herring family (Clupeidae), feed on molluscan larvae (Thorson, 1946). Moreover, many other holoplanktonic animals, such as small crustaceans and their larvae, polychaete worms, . . . which also constitute an important part of the diet of fishes, in turn feed upon larval lamellibranchs.

Beds of *C. virginica* are found in every state along the Atlantic and Gulf coasts of the United States. These oysters reproduce by discharging their gametes into the surrounding water, where fertilization occurs. In many southern states oysters are extremely numerous and their spawning continues through most of the year (Hopkins, 1954). The fecundity of oysters is remarkable; a single Long Island Sound female, only about 4 inches long, may discharge 70 million eggs in one spawning (Davis and Chanley, 1956). In the years when oysters develop thicker gonads they discharge more eggs.

Because many oysters usually participate in spawning on natural beds, most of the discharged eggs become fertilized and develop into swimming larvae. The larval period may be long, sometimes extending several weeks, depending on the temperature and quantity and quality of food. Therefore, the larval population constitutes an important and, in some years, long-available food item for many other forms. Because of these and other considerations it is evident that the eggs and

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larvae of oysters are important parts of the food supply of other aquatic animals, and that the significance of fluctuations in the quantities of spawn from year to year cannot be questioned.

Prytherch (1929) maintained that the prediction of time and intensity of setting of oysters in Long Island Sound could be made one month in advance, after careful analysis of several factors, one of which was the quantity of spawn accumulated by oysters. It was decided to undertake more detailed studies of this problem when we began to work in 1937—partly because Prytherch's conclusions were based on too short a period of observation, and principally because the literature contained little information on the accumulation of spawn in oysters, and its seasonal and year-to-year fluctuations. Our earlier observations in this field have already been reported (Loosanoff and Engle, 1940; Loosanoff and Nomejko, 1951a). Since then, however, much additional information has become available; this new material is the basis of the present article.

Methods

The usual method of estimating the relative quantity of spawn in oysters is to measure the thickness of the layer of their gonadal tissue, which practically surrounds the body of a ripe individual (Loosanoff and Engle, 1942). This method is reliable, however, only if the following two rules are followed: first, oysters of about the same size must be used; and, second, the cut through the gonadal layer always must be made through the same part of the oyster. This point is especially important because the thickness of the layer varies along the anterior-posterior axis of the body (Fig. 1).

We adopted a uniform method, which consisted of sectioning the body of the oyster on the right side, along the line extending through the stomach on a level with the lower edge of the palps; we then measured the thickness of the gonadal layer in millimeters, with calipers. At the beginning of our work the samples at each station included 6 to 10 oysters, but commencing with 1944 each sample was composed of 10 individuals. The oysters were from $3\frac{1}{2}$ to $4\frac{1}{2}$ inches long.

Data on the thickness of the gonadal layer of oysters are available for the entire 20-year period of the studies (1937–56). The analysis is limited, however, to 1944–56 (although reference is made to material collected over the entire period) because observations in those years were made at the same 10 stations and by the same individual, thus eliminating certain personal errors that might otherwise have been introduced.

The 10 stations were along the north shore of Long Island Sound, between New Haven Harbor and Bridgeport Harbor, at 10-, 20- and 30-foot depths. Since the description and the chart showing the location of these stations were given in a recent volume of this journal (Loosanoff, 1964), they are not repeated here.

Observations on conditions of oyster gonads were usually begun in May, at the beginning of the spring gametogenesis, and continued until the majority of oysters had spawned completely. The thickness of the gonadal layer was measured at approximately weekly intervals early in the season, but more often—sometimes even daily—as the start of spawning approached. These frequent measurements made it possible to determine accurately the dates on which the maximal thickness of the gonadal layer was attained.

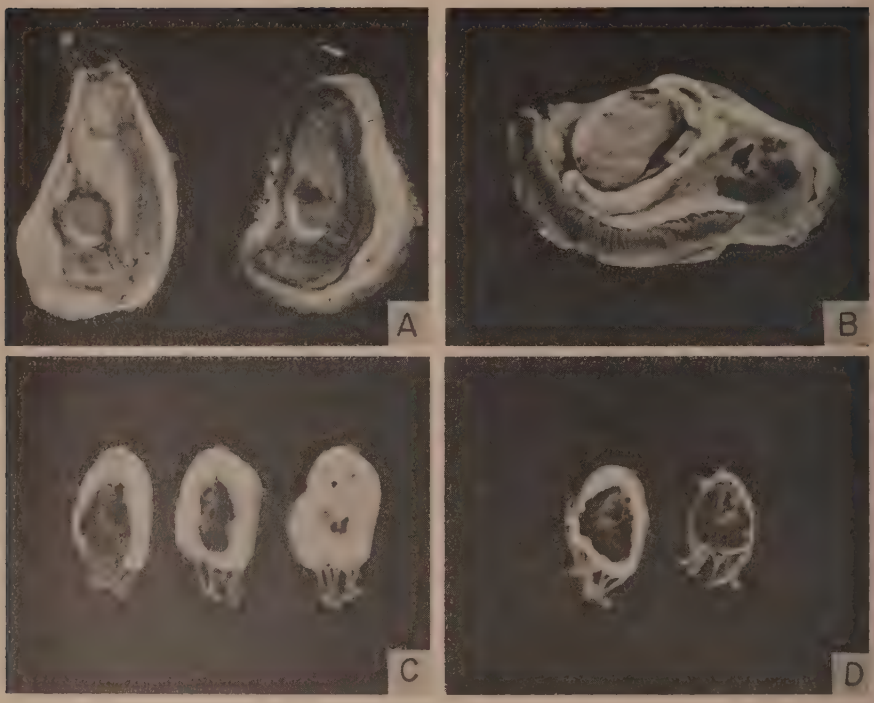

FIGURE 1. General condition of gonads of ripe and of spawned oysters. A. Ripe, unspawned adult oyster about 3½ inches long, with large, cream-colored gonad (left), and an individual with gonad almost completely discharged (right). B. Longitudinal section through body of adult oyster, showing well-developed, cream-colored gonadal layer surrounding digestive diverticula and stomach. C. Cross-sections through ripe oyster showing variation in thickness of the gonadal layer in different parts of the body. D. Cross-sections of two oysters at level of stomach: ripe individual with well-defined gonadal layer (left), and oyster that has discharged most of its spawn (right).

It should be mentioned that the maximal gonadal thickness referred to in this paper is not the average of the maximal values for each of the stations but the average of all the stations on the date of the highest grand average. Statistical analysis indicated, nevertheless, that these two measurements were similar, as is shown by the correlation between them of 0.97.

OBSERVATIONS

Gonads of *C. virginica* in northern waters undergo considerable changes during each year (Loosanoff, 1942). The fully developed gonad of an adult oyster is one of its most conspicuous organs and clearly distinguishes ripe individuals from unripe ones or from those that have already discharged all or most of their spawn (Fig. 1 A). The gonad is a virtually homogeneous, continuous mass surrounding the digestive tract and the digestive diverticula. Usually, a ripe gonad is cream-colored

(Fig. 1 B). The thickness of the gonadal layer, however, varies from one portion of the oyster body to another (Fig. 1 C). In spent individuals the layer is scarcely discernible (Fig. 1 D).

Histological studies of the gonadal tissue of Long Island Sound oysters have shown that during the cold season, when oysters are hibernating, their gonads are inactive (Fig. 2 A). The follicles are few and small and are found in the area between the body wall and the digestive gland, embedded in connective tissue. Nevertheless, the sexes can be distinguished even at this stage. In April, as the water temperature increases, spring gametogenesis is initiated and the follicles begin to enlarge, parallel with the increase in numbers of sex cells (Fig. 2 B). As the water becomes still warmer, proliferation and anastomosis of the gonadal follicles become more rapid, and late in May the follicles occupy a considerable space within the connective tissue. Toward the end of June most oysters in Long Island Sound are approaching ripeness (Fig. 2 C). At this time the larger part of the entire

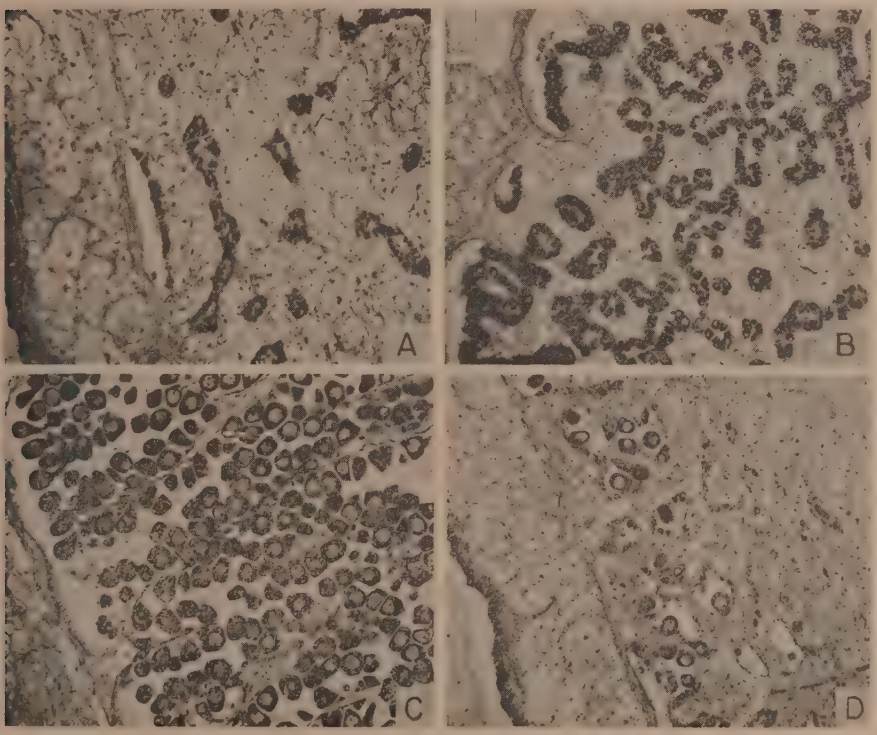

FIGURE 2. Seasonal changes in gonads of female oysters. A. Section of gonad in late spring, showing beginning of gametogenesis. Follicles, still in early stages of development, are surrounded by connective tissue (× 115). B. More advanced stage of ovogenesis, showing proliferation of follicles (× 115). C. Gonad containing eggs ready to be discharged (× 115). D. Gonad in advanced stage of spawning (× 75).

body is gonadal material, while the connective tissue, which so clearly predominated earlier in the season, has almost disappeared.

As is shown later, not all oysters begin to spawn at the same time, nor do they discharge their spawn at the same rate. Spawning of the same individual normally extends for many days or even weeks, although some oysters may discharge the gonads completely within a week after they begin to spawn.

Gonads in the late stages of spawning present a distinctive appearance, characterized by shrinkage of the follicles and invasion of a large number of phagocytic cells (Fig. 2 D). Reappearance of connective tissue also is normal during the late stages of spawning. A few unspawned eggs may be found in the shrinking follicles, but they will either be expelled later or be resorbed by phagocytes.

The date on which the maximal gonadal thickness was reached was determined for each station in each year from 1944 to 1956. At first it was thought that, instead

TABLE I

Dates maximal gonadal thickness was reached, and dates of various stages of discharge of the accumulated spawn by oysters of Long Island Sound, 1944–56

Year	Maximum thickness	Reduced to half maximum thickness	Days needed to reduce to half-thickness	50% of oysters more than half spawned	90% of oysters completely spawned
1944	7–21	8–4	14	8–5	8–24
1945	7–4	7–31	27	8–8	8–23
1946	6–27	8–1	35	8–1	8–28
1947	7–1	7–27	26	8–5	8–26
1948	6–30	8–3	34	8–5	9–4
1949	6–27	7–14	17	7–21	8–17
1950	7–19	8–20	32	8–16	9–6
1951	6–29	7–18	19	7–25	8–15
1952	6–30	7–16	16	7–31	8–20
1953	7–1	7–22	21	8–5	8–26
1954	6–30	7–24	24	7–28	8–24
1955	6–29	7–30	31	7–30	8–17
1956	7–6	8–16	41	8–22	9–5

of using the date of the single highest value, the date corresponding to the midpoint of the three highest values might be more reliable; when plotted, however, these two measurements were so close that it was decided to use the simpler measurement—the single date of the maximal gonadal thickness.

Dates of maximal gonadal thickness for the individual stations and years varied from June 20 to August 11; the average date was July 7. The average of all the stations for each year had the earliest date of June 27 and the latest of July 21 (Table I); the grand average (all years) was about July 4. Usually, the oysters of the New Haven stations reached their maxima first, followed by the Milford stations a day or so later, and then by the Bridgeport stations. As could be expected, oysters at 10-foot depths reached their maxima several days earlier than those at depths of 20 or 30 feet.

During the entire period of observation, 1937–56, the earliest date at which the start of spawning was recorded was June 26, and the latest was July 3. Within the 13-year period, 1944–56, these dates were June 26 and July 1.

It was established that in some years spawning began before the average maximal gonadal thickness was attained. The explanation is that, although some oysters were already emitting small quantities of spawn, the majority of them were not spawning at all but were continuing, instead, to accumulate gonadal material for several more days.

During the 20 years the average maximal gonadal thickness varied from approximately 4.1 mm. in 1937 to 1.6 mm. in 1946 (Fig. 3). We suspect that the unusual gonadal thickness reported in 1937 may not be properly descriptive. Possibly, errors in recording occurred at the beginning of our studies, when the

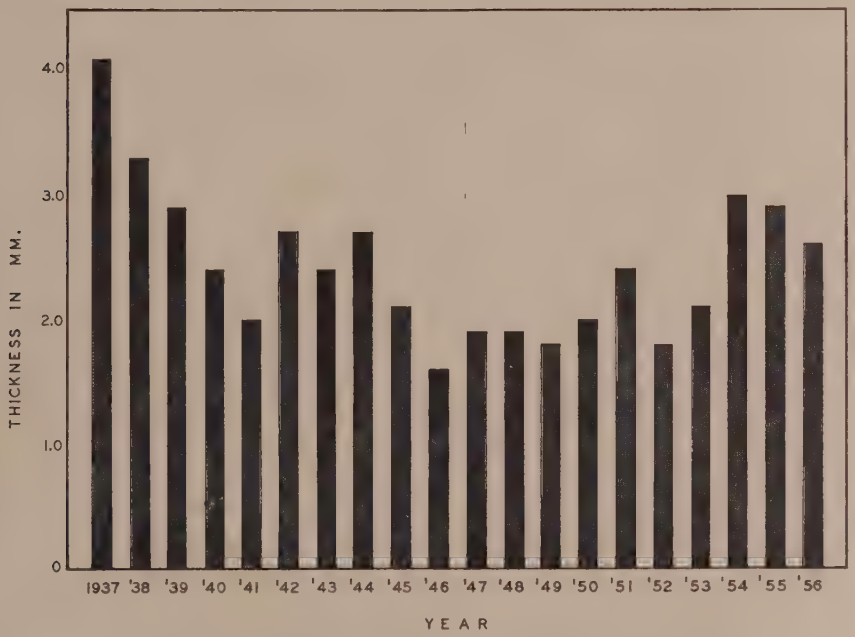

FIGURE 3. Average maximum thickness of gonadal layer of oysters, Long Island Sound, 1937–1956.

method was still being developed. Moreover, this high average was due, in part, to the unusually thick gonads recorded at one station, where they averaged almost 10.0 mm. The average maximum gonadal thickness for the 20 years was 2.4 mm.

From 1944 to 1956 the maximal gonadal thickness varied from 1.4 mm. to 3.9 mm. for individual stations in different years, and the grand average was 2.2 mm. (Table II). An analysis of variance shows significant differences for years and depths but not for districts. Average yearly maxima ranged from 1.6 mm. (1946) to 3.0 mm. (1954).

A comparison of the three areas revealed that oysters from New Haven, especially from its three shallowest stations, attained somewhat greater gonadal thickness before the beginning of general spawning than oysters of the Milford or

Bridgeport areas (Table II). This difference was slight, only about 0.1 mm., and, moreover, station 8, located at the 10-foot depth in the Bridgeport area, contained oysters with gonads just as thick as at the best station in the New Haven area.

Oysters growing at the depth of 10 feet developed, in general, much thicker gonadal layers than did oysters in deeper water (Table II). The difference between the gonadal thickness of oysters from 10- and 30-foot depths was about 0.4 mm., which under the circumstances may be significant. This observation agrees with our earlier finding that oysters living in shallow water developed much larger quantities of spawn than those living at greater depths (Loosanoff and Engle, 1942).

TABLE II

Maximal thickness (millimeters) of gonad layer of oysters collected at the same 10 stations, at 3 different areas and depths, Long Island Sound, 1944–1956

Areas	Milford			New Haven				Bridgeport			Average
Stations	1	2	3	4	5	6	7	8	9	10	
Depth (feet)	10	20	30	10	10	20	30	10	20	30	
Year											
1944	2.0	2.5	2.0	2.0	2.0	3.0	3.0	4.5	3.0	2.8	2.7
1945	2.5	2.0	1.8	1.9	2.6	2.4	2.2	2.2	1.8	1.4	2.1
1946	2.1	1.7	1.1	1.9	2.0	1.7	1.7	1.5	1.3	1.1	1.6
1947	1.7	2.2	2.0	1.8	2.1	2.2	1.8	1.6	1.7	1.7	1.9
1948	2.3	2.1	1.3	1.9	2.6	2.5	1.8	2.1	1.5	1.0	1.9
1949	2.1	2.2	2.0	1.6	1.5	1.6	1.7	1.5	2.2	1.9	1.8
1950	1.8	1.8	2.1	2.6	2.6	2.5	1.7	1.8	1.4	2.0	2.0
1951	2.5	2.1	2.1	2.2	2.5	2.3	2.4	2.9	2.6	2.5	2.4
1952	1.8	1.8	1.0	2.4	1.8	2.2	1.1	2.5	1.6	1.3	1.8
1953	2.6	2.3	1.3	2.3	2.6	2.5	1.7	2.4	1.8	1.5	2.1
1954	3.2	3.1	2.6	3.0	2.8	3.4	3.0	3.4	3.1	2.9	3.0
1955	2.9	2.9	2.7	3.0	3.1	3.2	2.8	2.7	3.1	2.9	2.9
1956	2.5	2.8	2.9	2.8	2.3	2.6	2.7	2.7	2.5	2.4	2.6
Station average	2.3	2.3	1.9	2.3	2.4	2.5	2.1	2.5	2.1	2.0	2.2
Area average	2.2			2.3				2.2			
Depth average	10 ft 2.4			20 ft 2.3				30 ft 2.0			

We still do not know why shallow-water oysters develop more spawn. The temperatures at the three depths varied only one or two degrees, a difference not significant enough to affect the metabolic processes of the oysters, especially their rate of feeding. It has been demonstrated that, in the wide temperature range from about 16° to 28° C., the rate of water pumping in oysters showed no great fluctuation (Loosanoff, 1958). The oysters may have accumulated more spawn in shallow water because the phytoplankton organisms they use as food were more abundant at that depth.

The increase in thickness of the gonadal layer prior to the state of ripeness and the release of the material during active spawning are relatively slow processes.

This fact is well illustrated in Table III, which shows average thicknesses of gonadal layers recorded at each sampling station during the entire 1956 season. These observations were begun before the gonads were thick enough to measure and were continued until they were almost spent.

The first measurable gonads were found about June 7, when the thickness of the layer varied from 0.1 to 0.4 mm. By the beginning of July, however, the layer at some stations was near or at the maximum. Thus, the major accumulation of spawn required 3 to 4 weeks.

After the beginning of spawning the thickness of the gonadal layer remained at about the same level for 12 or 14 days, but then it began to decrease (Table III).

TABLE III

Average thickness (millimeters) of gonad layer of oysters at each of 10 sampling stations, and average of all stations. Long Island Sound, May 31–September 5, 1956. Sample at each station was 10 oysters

Areas	Milford			New Haven				Bridgeport			
Stations	1	2	3	4	5	6	7	8	9	10	Average
Depth (feet)	10	20	30	10	10	20	30	10	20	30	
Date											
May 31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
June 7	0.0	0.0	0.10	0.35	0.40	0.35	0.15	0.0	0.10	0.10	0.16
13	0.50	0.75	0.60	1.55	1.45	1.60	0.65	0.0	0.40	0.25	0.84
19	0.80	1.40	1.40	1.70	1.70	1.55	1.35	1.15	0.90	0.70	1.27
28	1.95	1.95	1.80	2.70	2.80	2.15	2.10	2.15	1.95	1.80	2.14
July 2	2.25	1.90	2.25	3.45	2.30	2.15	3.15	2.75	2.05	2.35	2.43
6	2.50	2.80	2.85	2.75	2.30	2.55	2.70	2.70	2.50	2.40	2.60
10	2.75	2.60	2.65	2.60	2.35	2.45	2.65	2.45	2.55	2.65	2.57
18	2.70	2.35	2.20	2.35	2.15	3.05	2.75	3.00	2.70	2.70	2.60
25	2.65	1.95	1.55	2.10	1.40	2.00	2.55	3.15	2.35	1.85	2.16
Aug. 1	2.00	1.70	2.00	1.35	1.25	1.40	2.15	2.35	2.00	1.90	1.81
8	1.25	2.40	1.80	1.65	1.45	1.50	1.70	3.35	2.65	1.80	1.96
15	0.85	2.65	1.80	0.95	0.55	0.75	2.00	2.35	1.25	1.65	1.48
22	0.30	1.45	0.90	0.75	0.20	0.25	0.50	0.65	1.00	0.90	0.69
29	0.0	0.90	0.50	0.10	0.0	0.40	0.20	0.25	1.45	1.25	0.51
Sept. 5	0.0	0.05	0.15	0.05	0.0	0.0	0.0	0.0	0.20	0.0	0.05

Early in August the decrease was evident at all stations and depths. By late August and early September the gonads at some stations were so spent that they could not be measured.

The rate of spawn discharge varies considerably in different years. One criterion employed was the determination of the date when the maximum gonadal thickness was reduced to about half its original size. The earliest date this occurred was July 14, 1949, and the latest, August 20, 1950 (Table I). Thus, these two dates were more than a month apart, while the mean date for the 13-

year period was July 27. The number of days needed in different years to achieve this reduction varied from 14 in 1944 to 41 in 1956 (Table I).

The dates on which more than 50% of the oysters had passed the half-spawned stage ranged from July 21 in 1949 to August 22 in 1956 (Table I). The mean date was August 3, which may therefore be considered as approximately the mid-point of the spawning season of Long Island Sound oysters.

Another criterion used in studying the progress of the spawn discharge was establishment of the date at which 90% of the total oyster population was completely spawned. This date varied from August 15 in 1951 to September 6 in 1950, and the mean was August 25.

Further details on the rate of accumulation of sexual products, attainment of maximal thickness, and release of spawn by Long Island Sound oysters living at three different depths are given in Figure 4, which shows these conditions for 1946, 1950 and 1956. The year 1946 was characterized by relatively poor gonad development—maximal average thickness, only 1.6 mm. The gonadal layer of shallow-water oysters, however, was approximately 1.9 mm. thick. This figure was reached about June 27, but after that date the gonadal thickness of these oysters began to decrease rapidly and soon fell below the measurements recorded at the other two depths, especially at 20 feet.

In 1950 the gonadal layer developed rather rapidly, reaching almost complete fullness on June 28 (Fig. 4). Unlike 1946, however, the gonadal thickness at all three depths was about the same for a considerable period of time. As in 1946, however, the shallow-water oysters discharged their spawn sooner than those at the other two depths. The period when the average gonadal layer was at or near its maximum extended even longer than in 1946. Regardless of the greater accumulation of spawn in 1950, the spawning was nearly completed by September 6, only a week later than 1946.

The year 1956 was representative for the seasons when accumulation and discharge of gonad material by the oysters of all three depths progressed at about the same rate, and the quantities of spawn accumulated were nearly the same. The only appreciable difference was during the latter part of the spawning season, when the gonads of shallow-water oysters became spent somewhat earlier than did those of oysters at 20 or 30 feet. Moreover, development of gonads was better in 1956 than in 1946 and 1950; the average maximal thickness was 2.6 mm., approximately 0.4 mm. greater than the average for the entire period, 1944–56.

Loosanoff and Engle (1942) showed that individual oysters of Long Island Sound do not begin to spawn at the same time nor do they discharge their spawn at the same rate; ripe but unspawned individuals can be found as late as 6 weeks after the beginning of spawning, whereas some oysters may complete their spawning within the first week of the season. On the basis of these observations they concluded that, "It is possible that these individuals represent a race physiologically different from other local oysters whose spawning periods extend about two months." It was suggested that these individuals are descendants of the race of oysters brought to Long Island Sound from northern waters, where the spawning season is considerably shorter than in Long Island Sound.

Some other oysters, on the other hand, whose gonads late in summer were still thick, well-developed, and possessed ripe gametes, possibly represented races that

originated in the process of mixing oysters from many different points along the Atlantic coast, or were from southern races that required longer periods and higher temperatures than northern oysters for complete maturation and discharge of their sex cells. This conclusion was soon verified by experiments which demonstrated that oysters of different geographical regions display different temperature require-

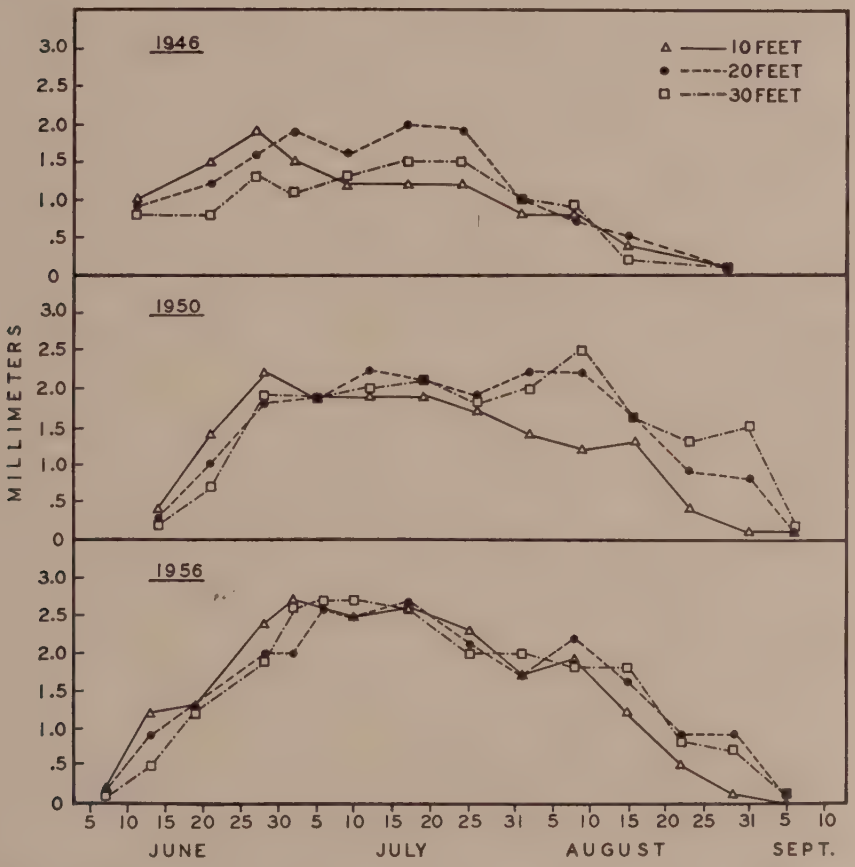

FIGURE 4. Average thickness of gonadal layer of oysters living at three different depths in Long Island Sound in 1946, 1950, and 1956.

ments for gonad development and spawning (Loosanoff and Nomejko, 1951b). A few months earlier Stauber (1950) offered an excellent theoretical discussion, which he based primarily on the observations of Hopkins (1931) and Loosanoff (1932), on the problem of physiological races within the general population of *C. virginica.*

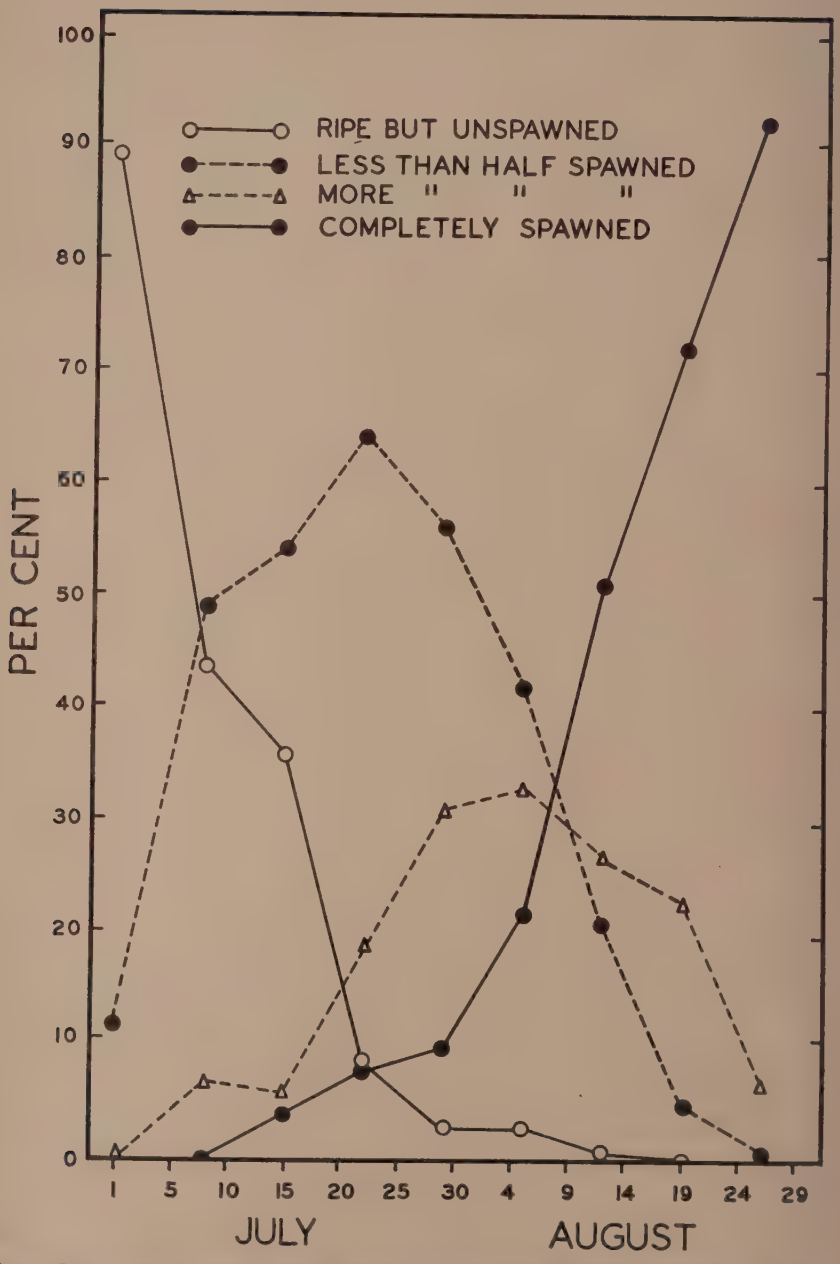

FIGURE 5. Percentage of ripe, partially spawned, and completely spawned individuals composing the oyster population at depths of 10 to 30 feet, Long Island Sound, July–August 1953.

The present studies fully support our earlier observations. Let us take 1953 as an example; when spawning began on July 1, only about 11% of the oysters showed partly discharged gonads, and the remaining 89% were still ripe but unspawned (Fig. 5). A week later only 44% of the oysters remained ripe but unspawned, 49% were less than half spawned, and the remaining 7% were more than half spawned. No completely spawned oysters were found on this date. They appeared first in samples collected on July 15, when about 4% of the oysters examined were completely spent. On that date, therefore, four different groups of oysters, namely, ripe but unspawned, less than half spawned, more than half spawned, and completely spawned, were found among the general population. From that date onward the percentage of completely spawned oysters increased rapidly, while the percentage of unspawned individuals became smaller and smaller until, on August 19, no unspawned individuals remained.

The observations in Long Island Sound have demonstrated, therefore, that even when the so-called "mass spawning" of oysters occurs, it does not involve the entire population, or sometimes even the majority. These field observations are strongly supported by the laboratory experiments of Davis and Chanley (1956), which show that not all oysters may be induced to spawn at the same time, and that, in general, spawning of an individual oyster is not a short-term process, during which the entire supply of sex cells is discharged, but, rather, a lengthy physiological effort which may continue for several weeks before an oyster is entirely spent.

As already mentioned, it is possible that in some aquatic basins the numbers of eggs and larvae of oysters may affect the survival and growth of planktonic organisms that feed on them. In that event, the ability to predict the total production of spawn of oysters and other lamellibranchs may be an important step toward the understanding of fluctuations in aquatic populations, including those of certain fishes. To ascertain such a possibility the data on gonad development of the oysters from 1944 to 1956 and the data on various biological and environmental variables recorded during the same period were subjected to conventional statistical analysis and to the computational techniques developed by the University of California at Los Angeles for biomedical programs for statistical analysis of biological data. All computations were made on a Burroughs B-5500 computer.

In evaluating the factors of the environment, which could be important in determining the quantities of spawn developed by the oysters in different years, two variables showed high correlations with maximal gonadal thickness. One was the departure of the average daily air temperature from normal during the period from September 1 to November 15 of the preceding year. This variable, to be indicated here as X_{at}, gave a correlation coefficient of 0.64. The second variable, X_s, the departure of percentage of possible sunshine from normal for the period indicated above, and maximal gonadal thickness gave a correlation of -0.80.

Since the intercorrelation of X_{at} and X_s was found to be -0.45, some improvement in prediction seemed possible by using a multiple correlation rather than the best single variable, air temperature. Accordingly, a multiple regression equation was computed to find the weighting of the two variables which would give the best prediction of the maximal gonadal thickness, X_{gt}':

$$X_{gt}' = -0.2021\, X_{at} + 0.0110\, X_s + 2.778.$$

The multiple correlation between the observed maximal gonadal thickness, X_{gt}, and the maximal gonadal thickness, X_{gt}', predicted from the weighted combination X_{at} and X_s, was 0.85.

Since N, the number of years during which observations were made, was 13 and the number of predictor variables was 2, the value of the multiple correlation

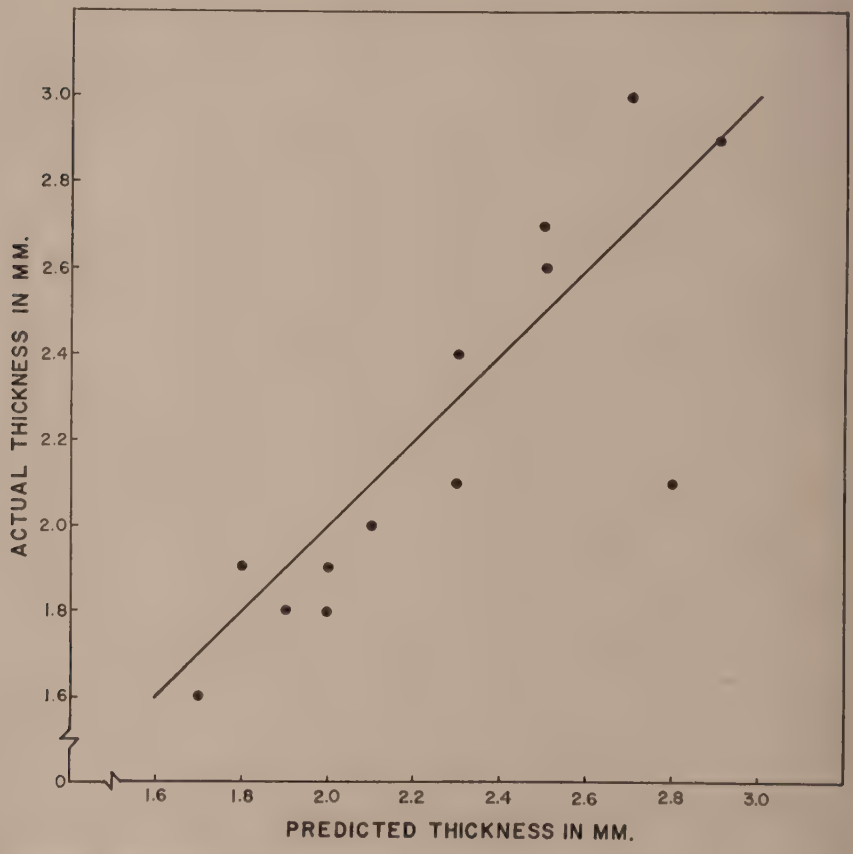

FIGURE 6. Relationship between actual and predicted maximal gonadal thickness in oysters of Long Island Sound over the 13 years, 1944–1956.

must be at least 0.78 for statistical significance at the 0.01 probability level. The actual multiple correlation of 0.85 exceeds this value; a good functional relationship between the two variables, *i.e.*, the predicted thickness and the observed thickness of the gonadal layer, is shown (Fig. 6). This relationship indicates that cool air and bright days during the preceding fall favor a greater accumulation of spawn by oysters during the succeeding summer.

Use of the multiple regression equation is always subject to criticism on the grounds that it capitalizes on high individual correlations which may be due to chance alone. If a very large number of potential predictor variables are tried, as in our study, some should yield statistically significant correlations by chance alone. It is possible, therefore (though not highly probable), that the apparently close relations between maximal gonadal thickness and the two environmental variables used for the prediction resulted merely by chance and do not represent true relationships.

The answer to this kind of criticism is not a statistical one but a biological explanation as to the meaning of this apparent relation. I offer the explanation that the combination of relatively low air temperature and bright, clear days between September 1 and November 15 of the preceding year is a favorable combination of environmental factors for the growth and reproduction of microplanktonic organisms eaten by oysters. At this time of the year the oysters of Long Island Sound store in their bodies most of the reserve material which, during gametogenesis the next spring, is converted into gonads. Thus, the more glycogen and other material accumulated the preceding fall, the greater is the thickness of the gonadal layer the following summer.

Since many examples are known in aquatic biology whereby apparently highly significant relationships between two or more variables failed to behave in the same manner soon after they were reported, I realize that the validity of my conclusions should be tested by further observations. It should be interesting, also, to ascertain whether my suggestions concerning the possibility of long-range prediction of the quantity of spawn developed by oysters of Long Island Sound are applicable to *C. virginica* of other geographical areas, and also to other species of oysters, especially of the genus *Crassostrea*, which was introduced to our Pacific coast and is the main commercial species of oysters in the waters of Japan.

I wish to express my thanks to Mrs. Barbara J. Myers for the statistical analysis of the data, to Charles Nomejko for his assistance during these studies, and to Mrs. S. Webb for her help in preparation of the manuscript.

Summary

1. During the 13 years, 1944–56, the average maximal gonadal thickness of oysters from Long Island Sound was attained between June 27 and July 21; the grand-average date was about July 4.

2. Gonads of oysters living at 10-foot depths reached their maximal thickness several days earlier than oysters living at stations 20 or 30 feet deep. Oysters of the New Haven area reached their maxima a day or so earlier than individuals of the Milford and Bridgeport stations.

3. Between 1937 and 1956, the earliest date at which spawning started was June 26, and the latest, July 3. In some years spawning began before the maximal gonadal thickness was attained.

4. Over this same 20-year period the average maximal gonadal thickness varied from approximately 1.6 mm. to 4.1 mm. and averaged 2.4 mm. In 1944–56, when observations were made at the same 10 stations, maximal thickness varied from

1.4 mm. to 3.9 mm. for individual stations, and had a grand average of 2.2 mm. Average annual maxima during this period ranged from 1.6 mm. to 3.0 mm.

5. Oysters growing at depths of 10 feet developed thicker gonads than did individuals in deeper waters.

6. The rate of spawn discharge varied considerably in different years. The earliest date at which the maximal gonadal thickness was reduced to about half its original size was July 14, and the latest, August 20. The number of days needed in different years to achieve this reduction varied from 14 in 1944 to 41 in 1956.

7. The days on which more than 50% of the oyster population was in more-than-half spawned stage ranged from July 21 to August 22. The mean date for this event, August 3, represents the approximate mid-point of the spawning season in Long Island Sound.

8. The date at which 90% of the oyster population was completely spawned varied in different years from August 15 to September 6, and the mean was August 25.

9. Recent observations support the previous conclusion that the oyster population of Long Island Sound is not homogeneous but a mixture of many physiological races.

10. Statistical analysis of the data suggests that the combination of relatively low air temperatures and bright, clear days between September 1 and November 15 of the preceding year is a favorable combination of environmental factors responsible for a larger accumulation of gonadal material the following summer. An explanation of this phenomenon, based on biological considerations, is offered.

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LANCASTER PRESS, INC., LANCASTER, PA.

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RESEARCH IN PESTICIDES
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Pesticides in Sea Water and the Possibilities of Their Use in Mariculture

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To a layman it may appear strange that marine biologists should be keenly interested in pesticides. Their concern becomes understandable, however, when it is realized that pesticides, as well as many of the other substances used on dry land, are eventually washed by the rain into the rivers and are finally carried into the oceans, or at least into estuarine areas, where the adult and larval stages of many aquatic forms are found.

The use of pesticides is not new; some were used centuries ago to get rid of fleas, bedbugs, and cockroaches, and most of us are familiar with the use of lime and copper in the vineyards of France. During the last quarter of a century, however, a new era in the discovery, production, and use of pesticides has begun. Because of the wide use of the new compounds, numerous problems concerning their effects upon aquatic environments have become of interest and significant importance to all marine biologists.

The effects of most pesticides now in use on dry land have never been studied on marine organisms. Nevertheless, there is evidence of contamination of aquatic environments by persistent compounds, such as DDT, because they have been found in fish caught considerable distances from dry land. We still do not know how some oceanic fishes accumulate DDT in their bodies, but there is little doubt that the organisms constituting the food chains are often carriers of the contaminants.

The U. S. Bureau of Commercial Fisheries is one of the oldest and largest research agencies in aquatic biology in the United States. Since it is concerned with virtually all aspects of aquatic communities, the Bureau could not remain indifferent to the use of new pesticides. Some of the earliest studies in this field were those of Ginsburg (1945), who reported the effects of DDT on fish; Sandholzer (1945), who studied the effects of the same compound on the blue crab (*Callinectes sapidus*) of the Atlantic coast; and Loosanoff (1947), who reported the effects of

DDT on the setting, growth, and survival of the eastern oyster *Crassostrea virginica*. Early studies by the Bureau of Commercial Fisheries in this field were summarized by Nelson and Surber (1947). The scope of these studies has gradually broadened, as the Bureau of Commercial Fisheries and its sister organization, the Bureau of Sport Fisheries and Wildlife, began to pursue extensive, well-developed programs of research. At present the Bureau of Commercial Fisheries is principally interested in the effects of pesticides on aquatic forms populating our estuarine and oceanic waters. The center of these studies is the Biological Laboratory, Gulf Breeze, Florida.

The problems facing marine biologists in connection with pollution of aquatic basins by different pesticides are numerous, and many groups of aquatic organisms may be affected, directly or indirectly, by changes in their environment due to the presence of recently developed substances, including insecticides, fungicides, and herbicides. I shall confine myself, however, largely to the results of our own work at the Bureau of Commercial Fisheries Biological Laboratory at Milford, Connecticut, of which I was Director when these studies were in progress. I shall also limit the discussion to the forms with which I am most familiar, chiefly marine invertebrates, principally mollusks and crustaceans, and emphasize the complexity of various situations that may arise in studies of aquatic communities altered by the introduction of new chemicals.

Our original interest in pesticides was aroused by the possibility that some of them could be used advantageously in controlling predators and competitors of commercial mollusks (Loosanoff, 1947). We still think that these substances may be of significant help to us and to our colleagues engaged in studies leading toward the development of more efficient methods of propagating and cultivating aquatic invertebrates of economic importance. We fully realize, however, the dangers of using pesticides in sea water, and we anticipate that numerous problems will be encountered during the course of developing safe, effective methods of chemical control in mariculture. Because the three-dimensional water environment supports a number of species having quite different tolerances, and because water is an excellent solvent of most materials, the use of chemicals under these conditions creates situations more complex than occur in agriculture. A knowledge of the effects on each species, as well as a knowledge of the possible changes in interrelationships among species, would be necessary for a full understanding of the effects of a chemical treatment.

The staff of Milford Biological Laboratory has been interested in all aspects of the ecology and physiology of larval and adult bivalves, especially oysters (*Crassostrea virginica*) and clams (*Mercenaria mer-*

cenaria). The food and feeding of these forms were therefore made the objects of our studies. Since these bivalves are filter feeders, depending chiefly on live phytoplankton, anything that would unfavorably affect the latter should also reflect on the existence of clams and oysters. Because of this consideration, studies were undertaken on the growth of five species of algae, in pure culture, in the presence of different organic toxicants (Ukeles, 1962). The tested species included two motile flagellates, *Monochrysis lutheri* and *Dunaliella euchlora*, which our earlier observations had shown to be among the best food organisms for oysters and clams and their larvae (Loosanoff and Davis, 1963). Two other phytoplanktonic organisms were nonmotile *Chlorella* sp. and *Protococcus* sp. The fifth species was *Phaeodactylum tricornutum*, a common form maintained in cultures at many marine laboratories and formerly known as *Nitzschia closterium*.

Ukeles (1962) found that all the species tolerated relatively high concentrations of organic phosphates, such as Dipterex and TEPP. For example, Dipterex at 50 parts per million (ppm) caused less than 50% inhibition in all instances. With TEPP there was no appreciable inhibition of cultures even at 100 ppm.

The effect of chlorinated hydrocarbons varied with the species of algae studied. For example, *Phaeodactylum tricornutum* and *Monochrysis lutheri* were seriously affected by 7.5 ppm of lindane, while other species were virtually undamaged. DDT, another chlorinated hydrocarbon, in colloidal solution at 0.6 ppm did not affect the growth of any forms tested except *M. lutheri*, the growth of which was slightly retarded.

Toxaphene was the most toxic of the chlorinated hydrocarbons tested. At a concentration of 0.15 ppm it was lethal to all five phytoplankton organisms. *M. lutheri* was especially sensitive to this compound and was killed by concentrations as low as 0.001 ppm. These results indicate, therefore, that pesticides, even though they belong to the same general group, may vary greatly in their effects on the same species of phytoplankton, and that different forms of phytoplankton may react differently to identical concentrations of the same compound.

Perhaps the most interesting part of Ukeles' studies was that devoted to the effects of the substituted urea compound herbicides, including fenuron, neburon, diuron, and monuron. Again, as with previous groups of chemicals, there was considerable difference in the concentrations necessary to affect the algae. The least toxic of the group was fenuron, tolerated at 0.3 ppm, while diuron and monuron were quite toxic, having a slight effect on the most sensitive species even at concentrations of 0.001 ppm.

In tests of weedicides, definite differences in sensitivity of the five

species of phytoplankton were again ascertained. The naked chrysomonad *Monochrysis lutheri* was the most susceptible of the group, and *Protococcus* was the most resistant (Ukeles, 1962).

The above-described experiments were usually conducted over periods extending from 10 to 14 days. It should be mentioned, as a matter of considerable interest, that cultures of *M. lutheri*, incubated for as long as 6 months in 1.0 ppm of Sevin or 1.0 ppm of lindane, were still capable of reproducing if transferred to media containing no toxicants.

Butler and Springer (1964) report that another, and very common herbicide, 2,4-D(2,4-dichlorophenoxyacetic acid), and its derivatives, when present in sea water in a concentration of 1.0 ppm, has little effect on the productivity of phytoplankton. However, Beaven *et al.* (1962), who used this compound in experiments to control undesirable aquatic weeds, Eurasian water milfoil (*Myriophyllum spicatum*), growing over oyster grounds in Chesapeake Bay, emphasized the danger of using such methods in an aquatic environment because the rapid decomposition of dead algae may cause extremely unfavorable conditions, killing most of the bottom-living forms, including oysters and clams.

The effects of pesticides on molluscan environments have also been subjects of our main studies. As early as 1945 we discovered that if shells, which are placed on the bottom as cultch to collect new generations of oysters, are sprayed with a solution of DDT in kerosene, this treatment will prevent setting of barnacles, serious competitors of recently set oysters (Loosanoff, 1947). At that time this was considered an important discovery in the field of shellfish culture because it could prevent the fouling of cultch. This method, as well as some modifications, was soon used in England (Waugh and Ansell, 1956) to protect oyster beds from excessive setting of *Elminius modestus*, an Australian barnacle accidentally introduced into European waters during World War II.

Later studies of the effects of this compound were rather important because they illustrated how much caution is necessary in using a foreign substance in an aquatic environment. For example, it was found that DDT is extremely toxic to oyster larvae and that when the concentration was only 0.05 ppm in sea water over 90% of the larvae died within 14 days (Davis, 1961). However, Davis pointed out, "The fact that oysters will set on shells treated with a substance as toxic to larvae as DDT indicates that chemicals, with the very low solubilities characteristic of many of these pesticides, can be safely used in controlling fouling organisms and predators if properly applied." Several years later it was shown that DDT in sea water may interfere with the shell growth of oysters (Butler and Springer, 1964). Thus, the studies on the use of DDT in

sea water clearly demonstrated that, although the use of pesticides in an aquatic environment may be advantageous in some respects, there are other aspects to be considered before a final conclusion concerning their use can be reached.

Work of Davis (1961) at Milford Laboratory on the effects of several concentrations of 31 pesticide compounds on the survival and growth of bivalve eggs and larvae is a highly informative contribution to our knowledge in this field. Davis tested these compounds on eggs and larvae of the American oyster, *Crassostrea virginica,* and the hard-shell clam of the Atlantic coast, *Mercenaria mercenaria.* Included were 14 insecticides, 4 herbicides, 4 organic solvents, and 9 compounds considered bactericides. The results emphasized once more that, to be properly evaluated, each compound should be studied individually. This is necessary because closely related chemical compounds, for example DDT and lindane, often affected bivalve larve of the same species to a different degree and in a different way.

Interestingly enough, Davis found that 12 of the 31 compounds induced, at one or more concentrations, a more rapid growth of larvae than was shown by larvae in control cultures. The compounds that caused the most pronounced increases in larval growth were thought to be bacteriostatic substances. Davis also found that clam larvae showed optimum growth at 5.0 ppm of lindane, a widely used insecticide. This should be contrasted with the observation that a related compound, DDT, as already mentioned, was usually fatal to oyster larvae at a concentration of 0.05 ppm. In general, Davis demonstrated that eggs of both species were capable of developing into normal larvae in higher concentrations of almost all the compounds tested than the larvae themselves could tolerate. Studies of this nature are being continued at Milford by Davis and his associates and are being gradually broadened to include observations on various detergents (Davis, personal communication).

Studies of the effects of pesticides on adult oysters, clams, and edible mussels are now conducted principally at Gulf Breeze Laboratory, Florida, under the direction of Dr. Philip Butler. According to him (Butler and Springer, 1964), the group of chlorinated hydrocarbons contains the most toxic pesticides affecting mollusks. A 50% decrease in shell growth of oysters was recorded during a period of 96 hours in concentrations of pesticides of this group ranging from 0.007 to 0.05 ppm. However, organophosphorus and carbamate insecticides were less toxic. The same was true of herbicides. When oysters were returned to unpolluted water they resumed their normal rate of growth within 2–4 weeks.

Studies at Milford have shown that oysters or clams exposed to certain compounds, such as chlorinated benzenes in which the insecticide

Sevin, a carbamate, was dissolved, would eventually accumulate these substances in their bodies (Loosanoff, 1962). When transplanted to pure sea water the mollusks would purify themselves, although with chlorinated benzenes this might require 2 or 3 months at a comparatively high temperature. The Sevin, however, may be eliminated entirely within 2 or 3 weeks.

Using our formula in natural bodies of water for control of undesirable gastropods, such as oyster drills, *Urosalpinx cinerea* and *Eupleura caudata*, (Loosanoff, 1960), our scuba divers noticed that the affected snails were in some instances eaten by fish. As already mentioned, this formula is a mixture of chlorinated benzenes, called Polystream, in which the carbamate Sevin is dissolved. In addition to gastropods, it affected certain worms and some other benthic forms eaten by fish. Such a condition may present a problem because, if the worms and other bottom forms on the treated area contain the chemicals composing the formula, these chemicals may later be incorporated in the bodies of commercial species of fish.

Butler (personal communication) and his co-workers at Gulf Breeze Laboratory found that Pacific and eastern oysters, as well as the common clam of the Atlantic coast, *Mercenaria mercenaria*, when kept for 40 days in water containing only 0.1 part per billion (ppb) of DDT, had accumulated in their tissues 7.0 ppm of this chemical by the end of the period. The chemical, however, was not evenly distributed throughout the oyster body, being more concentrated in certain organs. Approximately 67% of the DDT stored was in the oyster's intestinal tract and gonadal tissue, while the adductor muscle contained only 4%. Since the oysters are able to accumulate DDT residue 70,000 times as great as the amount present in surrounding waters in little more than a month, this fact is of considerably biological interest and, of course, of practical importance.

In other experiments oysters were exposed to flowing water containing 1.0 ppb of dieldrin, lindane, and heptachlor. By the paper-chromatography technique it was determined that after 60 days of exposure only dieldrin was present in oyster meats, in a concentration of 3.5 ppm; neither lindane nor heptachlor was detectable (Butler, personal communication).

Arthropods, especially crustaceans, were another group of marine invertebrates with which we were concerned in our pesticide studies because it is necessary to control some of them to protect our shellfish. For example, most crabs are dangerous predators of clams and oysters, especially when these mollusks are small. In some instances, when the crab population shows a sharp increase, a corresponding decrease in the

molluscan population may follow. Such was the case in the waters of Maine in the late 1940's, when the green crab *Carcinides maenas* became so numerous that it virtually eliminated, within a short time, the large population of soft clams, *Mya arenaria.*

In developing methods of control of these and other predators we screened several thousand compounds, looking for those that could be used to best advantage. Many compounds were found that affected crabs and other crustaceans which, directly or indirectly, endanger commercial mollusks (Loosanoff, 1960). Among these crustaceans were numerous copepods, which often invaded our mass cultures of phytoplankton grown as food for mollusks kept either in the laboratory or in outdoor tanks. We could quickly achieve complete extermination of these forms by using insecticides, e.g., Dipterex or TEPP. Because these insecticides hydrolyze rapidly to nontoxic products, they are particularly suitable for eradicating these pests from cultures to be used as foods for other invertebrates (Loosanoff *et al.,* 1957).

In other experiments, we found that the small crab *Pinnotheres ostreum,* which lives inside the oyster, often causing serious damage to its gills, can be controlled by spreading on the oyster beds certain chemicals, such as a mixture of Sevin and chlorinated benzenes. The same method was recommended and is now used on a large scale in Washington and Oregon to eliminate the mud shrimp, *Upogebia,* and the ghost shrimp, *Callianassa,* which render large areas of oyster bottoms entirely unfit for the oysters (Loosanoff, 1961). We also suggested to our European colleagues that the copepod *Mytilicola,* an extremely dangerous internal parasite of European oysters (*Ostrea edulis*) and mussels (*Mytilus edulis*), may be controlled by the chemicals we suggested (Loosanoff *et al.,* 1957).

During studies on the development of methods for controlling undesirable arthropods, it became increasingly clear how dangerous these chemicals may be in areas where useful aquatic arthropods or their larvae may be present. For example, in Chesapeake Bay the use of insecticides may seriously interfere with the normal existence of the blue crab *Callinectes sapidus,* an extremely important commercial species. The most serious problem in connection with insecticides in the water, however, is encountered with commercial varieties of shrimp in the Gulf of Mexico and other areas which come close to shore or enter estuarine areas where concentrations of pesticides may be high. It was found that concentrations of heptachlor, endrin, or lindane ranging from only 0.3 to 0.4 ppb killed or paralyzed, within a 40-hour test period, half of the adult commercial brown and pink shrimp (Butler and Springer, 1964). Chlordane, toxaphene, and DDT produced similar

effects at approximately 1.5 ppb. This sensitivity of shrimps to many insecticides indicates the danger of careless use of these substances in aerial mosquito control in salt marshes, where the young of many important crustaceans spend several months before migrating to waters more distant from shore.

We feel that we have sufficiently emphasized the point that pesticides in estuaries and coastal waters should always be considered with a great deal of suspicion since they may cause significant mortalities among aquatic populations. However, we also think that some pesticides, if properly used, can become important tools in mariculture. For example, our method of controlling boring gastropods, by using chlorinated benzenes mixed with sand spread on oyster bottoms, appears to be effective and relatively harmless to other species. Chemical control of green crabs in Maine, which destroy untold numbers of soft-shell clams, is another promising use of a pesticide that may be incorporated in maricultural practices. Control of undesirable crustaceans in mass cultures of algae is still another example of the possible use of pest killers in sea waters. Incorporation of certain chemicals in artificial collectors to gather considerably heavier crops of young oysters has already proved to be of great practical importance (Loosanoff, 1961).

We must keep in mind that, in North America alone, cultivated plants are attacked by over 3000 species of insects, plant disease organisms such as fungi, unestimated numbers of nematodes, as well as weeds and other competitors. There is little doubt that in the aquatic environment organisms destroying or unfavorably affecting commercially important species are also numerous. They may be pathogenic bacteria, fungi, and viruses; true parasites; predators, or merely competitors, such as barnacles and tunicates in the case of oysters. There is no question, therefore, that the use of pesticides in the aquatic environment will become increasingly common.

The majority of biologists agree that pests must be controlled. There is, nevertheless, a strong tendency in this group to think that we should rely on nature to control undesirable species. This idea is not new, and all of us experienced in economic zoology think at times in these terms. We must remember, however, that in agricultural practice biological methods of control have seldom worked, and as losses of crops reached disastrous proportions the people insisted on better and easier methods. Thus, scientists were reluctantly forced to enter the age of chemical pest control. This situation will probably exist for a long time.

In mariculture there are at present no really effective methods of protecting some valuable crops. For example, in many areas along the

Atlantic coast oystermen lose over 95% of recently set oysters because of predaceous snails, commonly called oyster drills. During recent years many formerly productive oyster beds have been abandoned because of drill activity. Our extensive experiments, conducted in the waters of Long Island Sound, in Great South Bay on Long Island, and in many other areas along the Atlantic coast, have clearly demonstrated that such sharecropping is no longer necessary. Most important—prevention of drill predation can be carried on without creating a biological desert. The method has been described on many occasions (Loosanoff, 1961) and is now being studied by the U. S. Public Health Service, the U. S. Department of Agriculture, and the Pure Food and Drug Administration. We hope that, within a short time, use of the basic principle and its modifications will be approved, with certain restrictions, for general use.

If our chemical method is eventually used routinely, this country, according to estimates by leaders of the oyster industry, may save between 15 million and 50 million bushels of oysters annually. We will need this extra food because our population is rapidly increasing.

We realize, and openly maintain, that virtually every foreign chemical that enters the water becomes a pollutant. We also declare that it is our duty as aquatic biologists to do everything possible to ensure that our rivers should still contain healthful, pure water and that the inshore areas and estuaries should not resemble septic tanks. However, since it is becoming increasingly clear that our civilization depends to a large extent on the use of synthetic compounds, condemning these substances completely would be impractical.

It is my opinion, as well as that of many other people interested in the same field, that the solution of our general problem lies in detection, isolation, and proper evaluation of different pesticides and, especially, in elimination of malpractices, rather than wholesale condemnation of pesticides and their uses. We should make a rule that any chemical to be used in an aquatic environment should be considered in terms of what it will do to the nontarget aquatic forms, to the general environment, and to the entire ecological communities in which the chemical is proposed for use. The decision should be reached only after extremely critical studies resulting in a comparison of the positive and negative qualities of the chemical. One of the purposes of such studies would be to determine the limits within which the chemical may be safely used.

We all agree that extensive systematic studies are necessary to overcome the difficulties which we face. These studies will be divided into many channels. Some will be devoted to the chemicals themselves and their structures because, after one finds an active molecular group-

ing, one can often improve it by modifying the original compound to make it less dangerous in some respects, with fewer undesirable side effects.

The above approach immediately suggests a search for chemicals that will not last long in the water. For example, in our efforts to control certain crustaceans in mass cultures of algae we found that commercial TEPP, containing 40% tetraethyl pyrophosphate, completely detoxifies in sea water within a few days. Such rapidly detoxifying compounds will permit us to control undesirable species without accumulating residues of these chemicals in commercial forms.

Discovery of chemicals of narrow specificity—those that will kill, for example, only one species of crab in a given environment without affecting other commercially important crabs—would be another method of restricting the side effects of a chemical treatment.

It should also be emphasized that studies of a short duration will not be sufficient to answer many of our questions. This is because traces of some compounds present in sea water, which during short-term experiments appear harmless, may in the long run accumulate in the organisms and either affect them directly or interfere with their ability to propagate. Long-range studies may also answer the question of whether some aquatic populations may develop resistance to certain pesticides. Observations on many successive generations may be needed to obtain this information. Studies of the synergetic effects of pesticides, together with common industrial pollutants, such as the wastes discharged into estuarine basins by pulp and paper mills, are also desirable.

In conclusion, I wish to repeat that, in our era, the use of pesticides cannot be avoided. We must make every effort, however, to use these chemicals as wisely and carefully as we can. All these substances are basically pollutants, and their presence in sea water is undesirable except when they serve a useful purpose, for example, fighting the plankton blooms which may endanger beds of commercial mollusks or perhaps even schools of fish.

We mariculturists are a small group. Yet, because of our nearness to the ocean and aquatic organisms, and because of our profound interest in all aspects of the existence of marine plants and animals, it is our responsibility to develop more modern methods for aquatic farming and, simultaneously, to prevent pollution of estuaries. I am certain that human genius will eventually provide us with successful solutions of our difficult tasks. These may be discoveries of new chemicals that will be much less dangerous than those now in use. I am expressing such hope because radical, advantageous changes are possible in most situations. For example, only a few years ago we were extremely concerned with hard

detergents because they are such stable compounds. These will soon be replaced by new, soft detergents that will quickly break down chemically after use. Thus, step by step we are overcoming difficulties that only a short time ago appeared insurmountable. This is why I believe that we will eventually discover and develop new pesticides that will be highly selective and highly effective, yet so unstable in their chemical nature that they will disintegrate within a few hours of use. Let us remember that only by finding new chemicals and developing new methods for their use can we expand farming of the sea and also protect our estuaries and their biological communities from undesirable pollution.

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CHRONIC EXPOSURE OF BLUE CRABS, *CALLINECTES SAPIDUS*, TO SUBLETHAL CONCENTRATIONS OF DDT

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Reprinted from ECOLOGY, Vol. 46, No. 6. Autumn 1965

CONTRIBUTION NO. 56 OF THE
BCF BIOLOGICAL LABORATORY
GULF BREEZE, FLORIDA

CHRONIC EXPOSURE OF BLUE CRABS, *CALLINECTES SAPIDUS*, TO SUBLETHAL CONCENTRATIONS OF DDT

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Abstract. Juvenile blue crabs, *Callinectes sapidus,* were reared in flowing seawater containing sublethal concentrations of DDT. Crabs fed, molted, and grew for 9 months in seawater containing 0.25 ppb (micrograms/liter) DDT but could survive only a few days in water containing DDT in excess of 0.5 ppb.

Commercially important marine crustaceans are extremely sensitive to many of the commonly used insecticides (United States Department of the Interior 1963, 1964), but preliminary studies show that blue crabs, *Callinectes sapidus,* will tolerate low concentrations of DDT for long periods.

This note describes the results of an experiment in which a small number of blue crabs was exposed continuously for 9 months to a sublethal concentration of DDT in flowing seawater. Such chronic exposures are of interest because blue crabs, especially the juveniles, spend much of their lives in shallow estuarine waters which may occasionally be polluted with insecticides.

This experiment was conducted at the Bureau of Com

mercial Fisheries Biological Laboratory, Gulf Breeze, Florida, between April and December 1964. Facilities are available for conducting bioassays in flowing seawater which is pumped directly from Santa Rosa Sound.

Six juvenile blue crabs averaging 27 mm in carapace width were placed in each of three plastic aquaria with a capacity of approximately 20 liters. Each aquarium was divided into six compartments, 150 × 150 mm, to prevent cannibalism and facilitate the keeping of records on individual crabs. Seawater flowed through each aquarium at a constant rate of 154 liters/hr. Acetone stock solutions of DDT were mixed in aspirator bottles and metered into two of the aquaria at a rate of 0.5 ml per minute to obtain the desired concentration. This constant-flow apparatus was illustrated in detail by Lowe (1964). The crabs in the third aquarium were maintained as controls with only seawater flowing through the aquarium. In preliminary bioassays blue crabs tolerated a significantly higher concentration of acetone in the test solution than was used in this experiment.

The crabs were fed frozen fish throughout the experiment. Pieces of fish flesh of approximately the same size were placed daily in each crab's compartment after the removal of any uneaten food. Additional food in the form of plankton was possibly obtained from the unfiltered seawater.

During preliminary screening tests juvenile blue crabs survived only a few days in flowing seawater containing DDT in excess of 0.5 ppb. Therefore, concentrations of 0.5 and 0.25 ppb were chosen as test solutions for the chronic exposures.

Although only 4 of 18 crabs (22%) survived the entire 9 months of captive life, most appeared to feed, molt, and grow normally. Records of molting and final size of individual crabs are itemized in Table I because of the paucity of this type of information in the literature. There was no difference in behavior between the control crabs and those in the 0.25-ppb DDT solution, but frequent observations of the crabs in the 0.5-ppb solution showed this concentration to be near the threshold of tolerance. Two of the crabs in the 0.5-ppb solution became paralyzed and died after 2 weeks of exposure. These and other crabs dying in the 0.5-ppb solution exhibited typical symptoms of insecticide poisoning (extreme irritability, increased sensitivity to external stimuli, and eventual paralysis) before death.

All crabs surviving the DDT exposure molted as frequently as the controls. One crab that survived the 0.5-ppb exposure and two from the 0.25-ppb concentration molted at least six times, the maximum number of molts for any of the control crabs. The average number of molts during the first 8 weeks of the experiment was 2.5 for the crabs in both the control and 0.25 ppb DDT; no deaths occurred during this period. The crabs surviving the entire 36 weeks of captive life occupied approximately 75% of their individual compartments and had barely enough room to move around. The size variation among individuals was as expected. Data on crabs from Chesapeake Bay show that linear measurements of an instar may vary by as much as 50% of the mean dimension (Tyler and Cargo 1963). Two of the crabs surviving 36 weeks of exposure to DDT were females; half-moon-shaped abdomens indicated the ultimate instar.

Table I. Survival and growth records of individual blue crabs held in captivity

Test solution	Initial carapace width (mm)	Weeks of survival	Total number of molts	Carapace width at death (mm)
Control	25	36	6	121[a]
	25	22	5	87
	25	20	4	61
	25	16	3	61
	28	12	3	50
	25	11	3	49
0.25 ppb DDT	27	36	7	130[a]
	27	36	6	137[a]
	20	29	5	90
	23	26	6	114
	28	17	4	71
	25	12	3	51
0.50 ppb DDT	29	36[b]	6	114[a]
	24	20	4	53
	25	8	2	48
	30	7	2	47
	25	2	1	—
	30	2	0	—

[a] Crabs alive at end of experiment.
[b] 23 weeks in 0.5 ppb followed by 13 weeks in 0.25 ppb DDT.

Any conclusions drawn from this experiment must be made with caution because of the small number of animals used. The data suggest that a natural crab population could exist in estuarine waters chronically polluted with low levels of DDT, but that a sudden slight increase in concentration could be disastrous.

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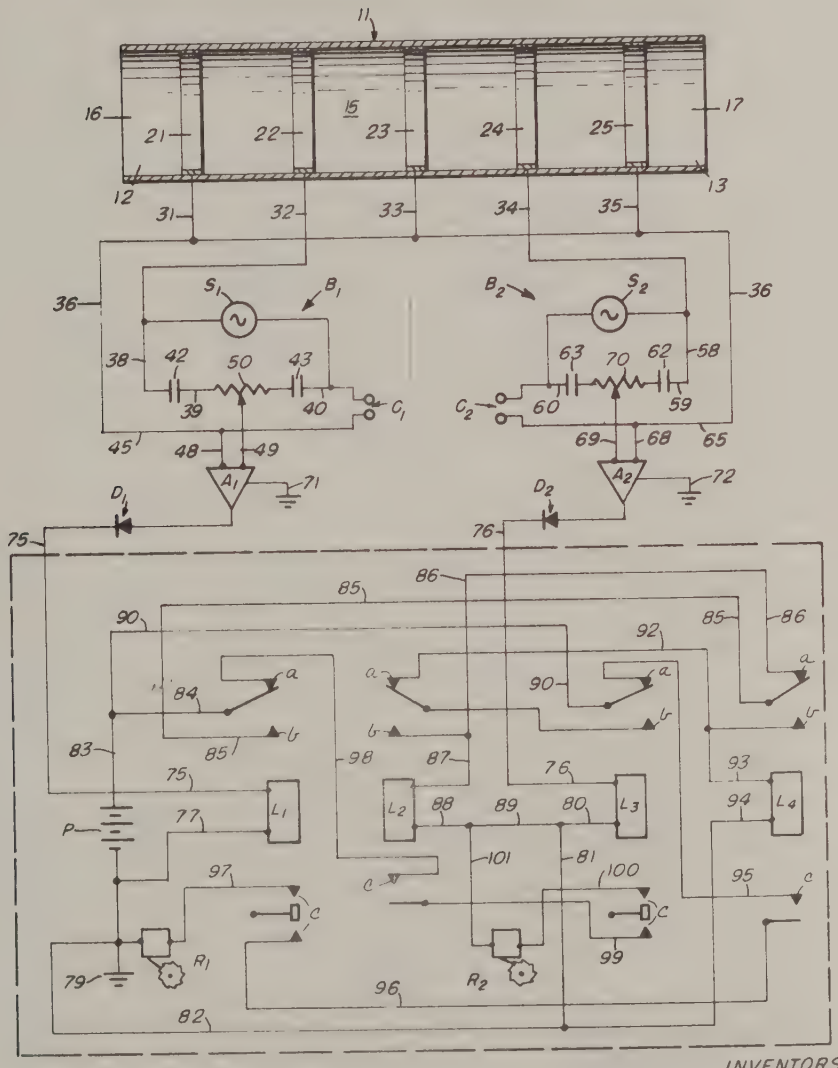
Dec. 14, 1965 G. M. LUCICH ETAL 3,223,319

MULTIPLE ELECTRODE DETECTOR

Filed Nov. 18, 1964 2 Sheets-Sheet 1

FIG. 1



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MULTIPLE ELECTRODE DETECTOR

Filed Nov. 18, 1964 2 Sheets-Sheet 2

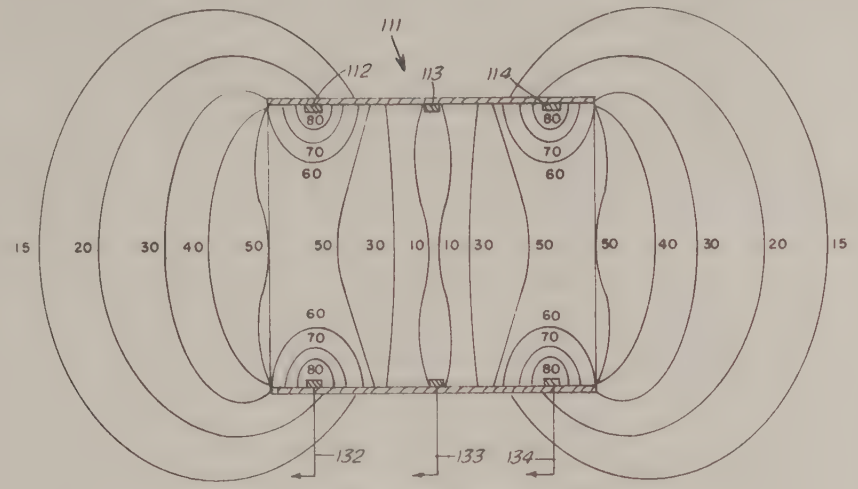

FIG. 2a

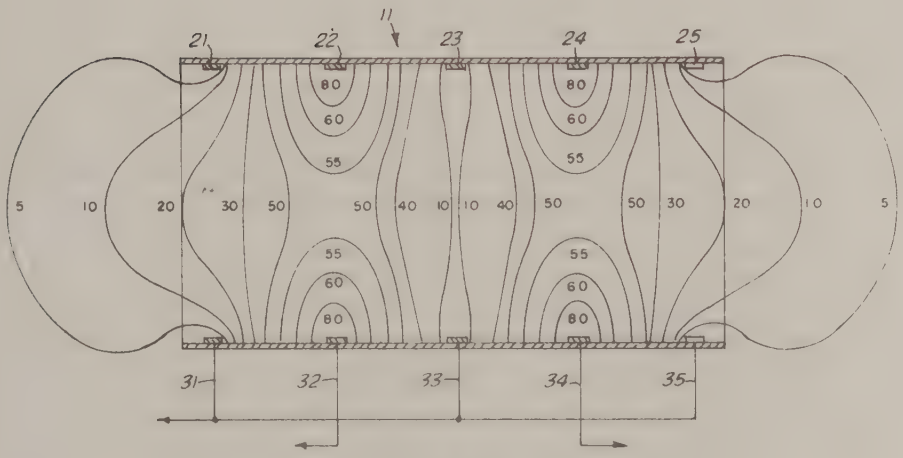

FIG. 2b

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3,223,319

Patented Dec. 14, 1965

3,223,319

MULTIPLE ELECTRODE DETECTOR

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Filed Nov. 18, 1964, Ser. No. 412,269
4 Claims. (Cl. 235—98)
(Granted under Title 35, U.S. Code (1952), sec. 266)

The invention herein described and claimed may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of royalties thereon or therefor.

The present invention concerns improvements in an electrical detector and indicator apparatus. More particularly, the improved apparatus operates to derive quantitative information relating to the passage of a substance through a medium confined within a component part of the apparatus by accomplishing a precise monitoring function upon the electrical conductivity of the substance in its association with the component part and an environment established therefor by the medium. Favoring the accomplishment of this cooperation in accordance with the present invention is the absence therein of any significant adversely disturbing effects which would ordinarily be imposed thereon by outside electrically conductive media in the vicinity of the component part. Of importance to enabling such cooperation is a specially designed passageway of the component part wherein three or more electrodes are uniquely arranged to be made operable when energized for controlling the activation of an electrical system which functions to derive and indicate relevant data upon the passage of the substance through the component part.

An apparatus according to the invention can be advantageously applied by having its passageway structure reside in a stream or other body of water where it is adapted to detect and indicate the presence of fish in the water which pass through the structure. As is more explicitly explained in the disclosure of Patent No. 2,893,633, issued to R. H. Van Haagen, on July 7, 1959, the utilization of fish detecting and indicating apparatus of the type disclosed herein, furnishes statistical information having importance to the management of fish hatcheries in providing an adequate census of stock, the testing of the adequacy of fish passing facilities, the management of sport fishing facilities in connection with data as to the abundance of stream fish at such facilities, as well as the operations of commercial fishermen in testing the efficiency of their traps. The hereinafter disclosed embodiment of the present invention utilizes for its passageway a tunnel structure in the same way as does Van Haagen, wherein such structure provides a restricted passageway for directing fish moving between adjacent bays in a stream, along a path which traverses a sequence of electrodes affixed to the inner surface of the tunnel structure. While Van Haagen's apparatus is generally satisfactory when applied under certain optimum conditions, the particular arrangement of electrodes disclosed in this patent for use in a restricted passageway, has limited applicability under many service conditions. The modifications which the disclosure of the present invention describes for the Van Haagen construction are singularly effective to overcome the limitations of the patented apparatus.

A further utility of the invention resides in its applicability for measuring the electrical conductivity of a fluid material moving through the passageway of its tunnel structure. Data produced by such measurements makes practical the monitoring of the conductivity of most flowing substances which in turn facilitates the making of a salinity profile of such a substance carried in any sort of conduit or pipe, or water carried along in a stream or an ocean current.

It is therefore an object of the present invention to provide for use in a fluid medium an improved detector in an electrical apparatus for controlling the operation of a system deriving and indicating electrical conductivity data.

A further object of the present invention is to provide for the control of a bi-directional registering system, an improved detector device which responds to variations in the electrical conductivity of media enclosed within the device.

These and other objects and advantages of the invention will be more clearly understood from the following description of a preferred embodiment of the invention considered together with the accompanying drawing wherein:

FIG. 1 schematically illustrates the tunnel structure according to the invention, and diagrammatically shows circuitry which is responsive to activity in the tunnel structure for controlling further circuitry, also shown, which determines the operation of indicating registers comprising a registering system; and

FIGS. 2*a* and 2*b* are diagrams of tunnel structures constructed according to the teachings of the prior art and the present invention, respectively, on which are graphically represented electrical phenomena occurring within these tunnel structures during their operation.

Tunnel structure **11** shown in FIG. 1 is essentially a tubular member **12**, made of plastic or any other electrically non-conductive material suitable for use under water. Tubular member **12** has a uniform cross-section along its full length, which may be circular, square, rectangular or any variant of these forms as required by the exigencies of the particular application for which the tunnel structure is intended. Wall **13** comprising the tubular member, is made sufficiently thick to provide structural integrity therefor. Opposite openings **16** and **17** in the tubular member **12**, which define between them a restrictive passage **15**, are made sufficiently large to accommodate for normal entry and passage therethrough, one complete fish at a time. On occasions when a heavy run of fish may cause more than a single entry into passage **15** at any one time, a statistical correction factor based on a visual count can be determined and applied to suitably revise the registered count upwardly.

Affixed to the inner surface of tubular member **12**, are five substantially identical electrodes **21** to **25**, inclusive. These electrodes are appropriately spaced parallel to each other whereby they are enabled to cooperate amongst themselves to produce electrical phenomena which are hereinafter more fully explained. Each such electrode is actually a ribbon of conductive material which is secured by cement or the like to the inner wall of the tubular member whereby they conform to the particular shape of that wall. The hoops or rings fashioned in this manner, may also be supported in shallow recesses formed in the inner wall of the tubular member. Lead-in connections to the separate electrodes are provided by the individual conductive leads **31** to **35**, inclusive, which are received through small bores in wall **13** opening on the electrode surfaces to which the leads are soldered. A further lead **36**, connected in common to the electrode leads **31**, **33** and **35**, completes a circuit in which the electrodes **21**, **23** and **25** can be maintained at the same potential. In practice lead **36** may be joined to extensions of the ground wire return provided by the shielding sheaths over the remaining electrode leads **32** and **34**. In that case, only two cables need extend out of the water for each of the tunnel structures placed therein, since each such cable carries a

connection for the common lead along with one of the leads directed to electrodes 22 and 24.

At the remote ends of the tunnel structure cables, the various leads therein are connected to a pair of impedance bridges B_1 and B_2. These bridges function in a conventional manner to compare potentials measurable across high resistance conductive paths between particular pairs of electrodes 21 to 25, against predetermined null producing potentials derived in the appropriate balancing arms of the bridges. As would be normally expected in the operation of such bridge circuits, changes in the potentials between the electrode pairs would make available in the bridging leads thereof, current outputs which can be directed to power control devices such as the conventional A.-C. amplifiers A_1 and A_2 shown in FIG. 1. Characterizing the arrangement of bridge B_1 are the arm defined by leads 36 and 32, comprising the electrode pairs 21, 22 and 22, 23, two arms defined by leads 38, 39 and 40, having in circuit therewith capacitors 42 and 43, respectively, and the arm comprising lead 45 and a balancing electrode pair C_1. By means of the further leads 48 and 49, amplifier A_1 is connected across bridge B_1 at an appropriate point between leads 36 and 45, and at a point on an adjustable balancing resistor 50, constituting the juncture between the arms defined by leads 38 to 40. Bridge B_2 is similarly formed by an arm defined by leads 34 and 36, comprising electrode pairs 23, 24 and 24, 25, two arms defined by leads 58, 59 and 60, having in circuit therewith capacitors 62 and 63, respectively, and an arm defined by lead 65 comprising a balancing electrode pair C_2. Further leads 68 and 69 are provided to connect amplifier A_2 across bridge B_2 at a point between leads 36 and 65, and at a point on an adjustable balancing resistor 70, constituting the juncture between the arms defined by leads 58 to 60. Alternating current power for energizing the sensing and detecting circuitry hereabove described, is supplied by suitable power sources S_1 and S_2, connected in a conventional manner across the further junctions at which are connected the arms of bridges B_1 and B_2, respectively.

A registering system for the invention as disclosed herein is provided by a register control mechanism CS comprising a logic circuit employing relays L_1, L_2, L_3 and L_4, which function to ultimately complete operating circuits for the actuating relays of a pair of rapidly responsive indicating registers R_1 and R_2. As is evident from the showing in FIG. 1, current signals emanating from amplifiers A_1 and A_2 are introduced to the control mechanism CS on separate leads 75 and 76 in which are operative rectifier diodes D1 and D2, respectively. Basically, it is these signals which control the energization of the logic relays whereby their switch elements are displaced to complete operating circuits for the separate registers. However, these relays respond only to a predetermined sequence of such signals so as to obtain an accurate bi-directional control wherein the individual registers R_1 and R_2 are selectively activated in accordance with the particular direction in which a fish traversed the tunnel structure 11.

Register control mechanism CS is essentially the same as that disclosed by Van Haagen in the patent previously identified. A separate D.-C. source P is provided to energize relays L_3 and L_4, as well as the actuator relays of registers R_1 and R_2, when their energizing circuits are completed. On the other hand, relays L_1 and L_3 are directly energized by amplifiers A_1 and A_2, respectively, in circuits completed through the ground connections 71, 72, in the output circuits of the amplifiers. Relays L_1 and L_3 each have a single-pole, double-throw switch element displaceable between a normally closed contact *a*, and a normally open contact *b*, and a special switch element which momentarily closes a contact *c* only upon a change in the energization state of the relay, such as when the relay is energized or deenergized. Relays L_2 and L_4, each have a single-pole, double-throw switch element displaceable between a normally closed contact *a* and a normally open contact *b*, and a single-pole, single-throw switch element displaceable to close a normally open *c* contact. Relays L_1 and L_3 also differ from their complementary relays L_2 and L_4, in that upon their energization, the former respond to displace their switch elements about three times faster than do the latter.

An energization circuit for relay L_1 is traceable on leads 71, 75, 77, 78 and 79, which provide a current path between amplifier A_1 and the relay. A similar circuit for relay L_3 is traceable on leads 72, 76, 80, 81, 82 and 79, which provide a current path between amplifier A_2 and relay L_3. Relay L_2 is energized when a current path is completed between it and power source P, on leads 83, 84, contact L_{1b}, lead 85, contacts L_{4a}, leads 86, 87, 88, 89, 81, 82 and 78. Relay L_4 is energized when a current path is completed between it and power source P on leads 83, 90, contact L_{3b}, lead 91, contact L_{2a}, leads 92, 93, 94, 82 and 78. The actuating relay of register R is energized when a current path is completed between it and power source P on leads 83, 90, contact L_{3a}, lead 95, contact L_{4c}, lead 96, contact L_{1c}, leads 97 and 78. The actuating relay of register R_2 is energized when a current path is completed between it and power source P on leads 83, 84, contact L_{1a}, lead 98, contact L_{2c}, lead 99, contact L_{3c}, leads 100, 101, 89, 81, 82 and 78.

As was previously indicated, amplifier A_1 produces an output in response to changes in the electrical conductivity between electrodes 21 and 22, or electrodes 22 and 23. It is evident that either or both such changes act to unbalance bridge B_1 whereby the current then caused to flow in the circuit of leads 48 and 49, activates the amplifier. A sensitive balance is attained initially for bridge B_1 by means of the conductive electrodes pair C_1 which when placed in the water at some distance from the tube member 12, provides in its bridge arm a load that is equivalent to that obtained in the arm loaded by the circuits made through undisturbed conductive paths between electrodes 21, 22 and 23. The loads in the arms comprising capacitors 42 and 43, respectively, are brought to a balance by means of the voltage division effect accomplished therein in an obvious manner by suitably positioning a contact slider on adjustable resistor 50. Bridge B_2 is initially conditioned to a sensitive balance in the same way, by means of its balancing conductive pair C_2 and its adjustable resistor 70. Consequently, bridge B_2 reacts to supply current to the circuit of leads 68, 69, and amplifier A_2, when the bridge detects a change in the electrical conductivity between pairs of electrodes, 23, 24 and 25.

With reference once more to tunnel structure 11 of FIG. 1, it can be seen that during its operation in the grounded conductive medium under water, the electrodes 21 and 22 thereof, cause to be effective a conductive path having relatively high resistance at or about electrode 21, and relatively low resistance at or about electrode 22. For example, the medium constituting the conductive path may be viewed as a uniform resistance element in a circuit completed between electrode 22 at the potential of course S_1, and electrode 21 at the ground potential of the medium. It is evident therefore that since electrode 21 is at the potential of the medium, resistances measured at points along the conductive path established by the medium, increasingly distant from electrode 22, accordingly increase. Consequently, a fish moving from left to right and passing into opening 16 of tunnel structure 11, whereby it enters only the hoop of electrode 21, produces little or no significant effect on bridge circuit B_1. Manifestly, the presence of the somewhat lower resistance of the fish body, which displaces a part of the higher resistance medium in the conductive path, at only the high resistance area about electrode 21, does not cause a sufficient change in the conductivity of the path as to disturb bridge B_1. However, as the fish traverses the path between the electrodes 21 and 22, and enters the hoop of electrode 22, the lower resistance fish body displaces medium all along the conductive path. As a result, the arm of bridge B_1 compris-

ing these electrodes, measures increased currents in their conductive path. The subsequent unbalance in bridge B_1 allows current to flow in the circuit of amplifier A_1 which thereupon provides an output to lead **75**.

Output current from amplifier A_1 flows in a circuit completed through leads **71**, **75**, **77**, **78** and **79**, whereby relay L_1 is activated to close contacts at L_{1b}, and momentarily close contacts at L_{1c}. Since the L_{4c} contacts are then open, the momentary closure of L_{1c} does not operate register R_1. However, a circuit to energize relay L_2 is completed to D.-C. power P, through contacts closed at L_{1b}, leads **83**, **84**, **85**, normally closed contacts L_{4a}, and leads **86**, **87**, **88**, **89**, **81**, **82** and **78**. However, the resultant closure of the L_2 relay contacts at L_{2b} and L_{2c} are ineffectual since contacts at L_{3b}, and L_{3c} in circuit therewith, remain open.

Further movement of the fish through tunnel structure **11**, to enter the hoop of electrode **23**, does not change the then existing state of the circuits since any further unbalance in the bridge arm comprising electrode pair **22** and **23**, merely continues current output from amplifier A_1, and the energization of relays L_1 and L_2. Upon its passage into the hoop of electrode **24**, the fish provides its lower resistance body to form the media establishing a conductive path between electrode pair **23** and **24**, in addition to a conductive path between electrode pair **22** and **23**. Consequently, bridges B_1 and B_2 are then both brought to an unbalance, causing their respective amplifiers A_1 and A_2 to each produce an output. As a result, relay L_3 is energized in a current path completed through leads **72**, **76**, **80**, **81**, **82**, and **79**, whereby L_3 closes its contacts at L_{3b}, and momentarily closes its contacts at L_{3c}. A holding circuit for relay L_2 is thus completed through to the D.-C. power source P, by means of the closed contacts L_{3b} leads **83**, **90**, **91**, closed contacts L_{2b}, and leads **87**, **88**, **89**, **81**, **82** and **78**. The contacts closed at L_{3c} do not operate register R_2 since contacts L_{4c} remain open.

Moving further to the right, the fish enters the hoop of electrode **25**, and leaves the immediate vicinity of elctrodes **21** and **22**. The action following this move, includes the deenergization of relay L_1 since bridge B_1 is no longer held unbalanced, and the output from amplifier A_1 has ceased. Consequently, the contacts at L_{1b} open, and those at L_{1a} close. Although contacts L_{1c} momentarily close on deenergization of relay L_1, there is no effect on register R_1 since contacts at L_{4c} remain open. Relay L_2 remains energized through its holding circuit. Passage of the fish out of electrode **24** does not effect the unbalance state of bridge B_2, and amplifier A_2 continues to furnish its output to the circuits of the register system. Thereafter, when the fish leaves the tunnel structure by passing out of the hoop of electrode **25**, balance is restored to brdge B_2, and output from amplifier A_2 also ceases. Relay L_3 is thereupon deenergized to switch its contact arm away from L_{3b} and back to L_{3a}. Moreover, the contacts at L_{3c} momentarily close to complete an energizing circuit from D.-C. power P to the actuating relay of register R_2, through leads **83**, **84**, normally closed contacts at L_{1a}, lead **98**, closed contacts L_{2c}, leads **99**, **100**, **101**, **89**, **81**, **82** and **78**. This circuit to register R_2 is completed even though the holding circuit for relay L_3 is opened at contacts L_{3b} when relay L_3 is deenergized. It should be recalled that relay L_2 is relatively slow acting in comparison to the responsiveness of relay L_3, with the result that in spite of the open circuit to relay L_2, this relay does not act to switch its contact arm at L_{2c} until after the contacts at L_{3c} have momentarily closed to complete the power circuit which operates the actuator solenoid in the register.

From the foregoing, it should be clear that each fish passing from left to right through the tunnel structure **11**, adds a count to register R_2. Because of the basic symmetry of the various detector, control, and register operating circuits constituting the arrangement of FIG. 1, it should be equally clear that each fish passing from right to left through the tunnel structure would cause an operational sequence analogous to that above described, and add a count to register R_1. It should also be apparent that in no event would a count be added to either register unless the fish had effectively traversed the full length of the tunnel structure. If any substantial portion of the fish body resides between electrodes **21** and **22**, or electrodes **24** and **25**, the bridge circuit corresponding to the affected electrode pair remains unbalanced to provide current to energize relays L_3 or L_1, as the case may be, whereby the registers are maintained inoperative. Any fish having a terminal part thereof substantially in or beyond the hoop of electrodes **21** or **25**, can be considered to have traversed the tunnel structure since the fish is effectively compelled by the quite restrictive openings **16** or **17** of the tubular member **12**, to continue in a path outside this structure.

A tunnel structure **111**, in FIG. 2*a*, characterized by an arrangment of three electrodes **112**, **113** and **114**, represents as was hereinbefore indicated, prior art. Bridge circuits in the nature of that shown in FIG. 1, are operatively associated with this tunnel structure by means of leads **132**, **133** and **134**. Electrode **112** and **114** are in separate circuits, completed through leads **132** and **134**, which directly connect these electrodes to the respective power supplies of the bridges, and electrode **113**, in a circuit including lead **133**, is joined to both bridge circuits by connections corresponding to those shown in FIG. 1 associating common return lead **36** with bridge circuit B_1 and B_2. During operation of tunnel structure **111**, central electrode **113** coacts with both electrodes **112** and **114** to constitute electrode pairs **112**, **113** and **114**, **113**. As was hereinbefore explained, the resistance of the conductive path between paired electrodes varies from a maximum at the return electrode to a minimum at the electrode circuited directly to the power source in the bridge circuit. Accordingly, the resistance between electrodes **112** and **113**, and between electrodes **114** and **113**, diminishes approaching electrodes **112** and **114**, respectively. Consequently voltage measurements taken between the common electrode **113**, and various points in conductive paths approaching electrodes **112** and **114**, manifest gradually increasing voltages, with the maximum voltages being measureable at points in the immediate vicinity of electrodes **112** and **114**.

The graphical lines shown in FIG. 2*a*, represent cross sections of equipotential surfaces between the paired electrodes. The scale or from 100 to 0, applied in FIG. 2*a* to identify the lines, is indicative of the existing voltage gradients varying from maximum to minimum between the respective electrodes **112** and **114**, and common electrode **113**. Furthermore, since the medium in which the tunnel structure is installed, is conductive and at the potential of electrode **113**, significant voltage gradients are seen in FIG. 2*a*, to exist between the respective electrodes **112** and **114**, and points in the medium at substantial distances outside and around the openings in tunnel structure **11**. This spread of conductive paths outside the tunnel structure is ordinarily a source of serious difficulties to a proper operation of a fish counting apparatus. Events that have little to do with the passage of fish through the tube such as the conductivity of structural objects in the vicinity, the movement of fish in the vicinity, the proximity of the water surface, and the nature of the bottom materials cause erroneous counter operation. These factors also contribute to the instability of the counting system which is manifested by a "drift" in the null or balance of the bridge circuits. Attempts to overcome the difficulties inherent it the use of a three element tunnel structure such as shown in FIG. 2*a*, often required all adjacent metal structures to be insulated, and the installation of extra structures outside the tunnel structure at such

points where fish might swim near the exterior of the structure.

FIG. 2*b* illustrates by its graphical lines the voltage gradient contours characterizing electrical phenomena in and around the tunnel structure of the present invention. Because the outer or end electrodes of this tunnel structure are at the return potential, or that of the medium, the existing voltage gradients to points outside the tunnel structure are quite inconsequential. Therefore, tunnel structures according to this construction are found to have practically all of their points of effective voltage in conductive paths confined within the non-conductive tubular members comprising these structures. In addition, there is a more linear distribution of the voltage gradients within such tunnel structure. The structure is practically free from the effects of random changes outside its tubular member, including surface wave action close to the top of the structure. There is also an increased stability and sensitivity in its detector circuits which result in less critical and less frequent adjustments of such circuits, permitting semiskilled helpers to use this type of counting apparatus in the field.

Since significant outputs from either detector circuit shown in FIG. 1 occurs in response to a change in the conductivity of substances passing through the tunnel structure, it can be readily understood that the present invention is easily adaptable for detecting and measuring the conductivity characteristics of such substances. Moreover, since one detector circuit need be used in an operation of the invention for this purpose, circuitry also pertaining thereto includes two conductive leads from the tunnel's first or last three electrodes to two opposite junctions of the appropriate detector circuit, and conductive leads from the other two opposite junctions of the detector circuit connected to a conductivity indicator such as a galvanometer. Proper components are selected for use in the bridge arms of the detector circuit to determine a base or index value of conductivity, and the galvanometer is accordingly calibrated therefrom in a conventional manner. With the tunnel structure located in the flow path of a stream, or periodically placed therein in a predetermined sequence, observations of the calibrated galvanometer can be taken at appropriate times to obtain readings representing conductivity or salinity data. The representative signals in the galvanometer circuit can obviously also be directed to an amplifier operating a recorder, or accomplish other similar control functions.

While particular embodiments of the present invention have been illustrated and described herein, it will be understood that this invention is not limited thereto, but is susceptible to change in form and detail.

What is claimed is:

1. In an electrical apparatus for measuring a representative characteristic of a conductive substance moving in a confined space, a detecting circuit, and a sensing means comprising a non-conductive conduit device having openings at its opposite ends between which is defined said confined space, a plurality of electrically conductive ribbons spacially arranged on non-contiguous areas on the inner surface of said conduit device, a plurality of electrical conductors providing electrical connections between said conductive ribbons and said detecting circuit wherein at least two of said electrical conductors are joined to establish a common conductive path in which electrical current from at least two of said conductive ribbons flows directly to said detecting device, and another of said electrical conductors provides a singular path in which electrical current from another of said plurality of conductive ribbons flows directly to said detecting circuit.

2. In an electrical apparatus for detecting and registering the passage of discrete masses through a conductive medium in a confined area, having register operating control circuits, a sensing means comprising a non-conductive shell having opposite end openings and defining therein the said confined area, and at least five conductive elements spacially arranged in said shell and operable when energized to establish current flow in a plurality of conductive paths through said conductive medium, a pair of detecting circuits each of which is electrically connected to at least two adjacent ones of said conductive elements and said register operating control circuits, said detector circuits being responsive to the passage of a discrete mass into an opposite end opening of said shell and along said conductive paths having current therein, to produce signals which activate the register operating control circuits.

3. In the apparatus of claim 2, each of the detecting circuits comprising an impedance bridge in which a source of power and an amplifier are respectively connected across different opposite junctions joining the arms of said bridge, and at least one pair of said adjacent conductive elements being in a circuit constituting one of said bridge arms.

4. In the apparatus of claim 2, each of the detecting circuits comprising an impedance bridge in which a source of power and an amplifier are respectively connected across the different opposite junctions joining the arms of said bridge, and at least three of said conductive elements in said shell being in a circuit constituting one of said bridge arms, whereby one of said three conductive elements adjacent to the other two, is conductively joined to a junction of said bridge connecting the said power source thereto, and the said other two conductive elements are joined to a junction of said bridge connecting the same amplifier thereto.

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MALCOLM A. MORRISON, *Primary Examiner.*

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Experimental Control of Sea Lampreys with Electricity on the South Shore of Lake Superior, 1953-60

reat Lakes Fishery Commission

CHNICAL REPORT No. 10

The Great Lakes Fishery Commission was established by the Convention on Great Lakes Fisheries, between Canada and the United States, ratified on October 11, 1955. It was organized in April, 1956 and assumed its duties as set forth in the Convention on July 1, 1956. The Commission has two major responsibilities: the first, to develop co-ordinated programs of research in the Great Lakes and, on the basis of the findings, recommend measures which will permit the maximum sustained productivity of stocks of fish of common concern; the second, to formulate and implement a program to eradicate or minimize sea lamprey populations in the Great Lakes. The Commission is also required to publish or authorize the publication of scientific or other information obtained in the performance of its duties.

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EXPERIMENTAL CONTROL OF SEA LAMPREYS WITH ELECTRICITY ON THE SOUTH SHORE OF LAKE SUPERIOR, 1953-60

by

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1965

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EXPERIMENTAL CONTROL OF SEA LAMPREYS WITH ELECTRICITY ON THE SOUTH SHORE OF LAKE SUPERIOR, 1953-60

Alberton L. McLain, Bernard R. Smith
and Harry H. Moore

ABSTRACT

Experimental control of the sea lamprey, *Petromyzon marinus*, with electric barriers was begun in Lake Superior in 1953. Electrical devices were the most practical and promising method of control then available. Installed below spawning grounds in streams and rivers tributary to Lake Superior, these barriers were designed to prevent the sexually mature sea lampreys from reproducing.

The catch of sea lampreys at the electric barriers increased rapidly from 1,668 in 1953 to 66,931 in 1958. The total catches dropped substantially in 1959 and 1960 to 52,173 and 39,783, respectively.

Electric fields of sufficient intensity to block sea lampreys were potentially lethal to other fish and caused undesirable mortality. Improvements in design and installation, and the development of a direct-current diversion device reduced the mortality and increased the efficiency of operation.

The development of control by selective chemicals in 1958 superseded the barrier control system which was terminated at the end of the 1960 season.

The electric barrier operation provided considerable information on mature sea lampreys, including data on time of migration, length, weight, and sex composition.

Electric devices of the type and design used are capable of blocking entire runs of adult sea lampreys. An accurate appraisal of the effectiveness of the barrier system is impossible, however. Most of the barriers were not operated long enough to reduce the contribution of parasites from the streams. Furthermore, a complete system of efficient electric barriers was never realized. The greatest weakness of this method of control lies in maintenance of the units in continuous, uninterrupted operation through consecutive migratory seasons.

Introduction

The search for means to control the sea lamprey, *Petromyzon marinus*, in the Great Lakes led to the development of electric barriers and traps (Applegate, Smith, and Nielsen, 1952). These devices, first built and tested in streams tributary to northern Lakes Huron and Michigan, were designed to prevent reproduction by blocking the upstream migration of sexually mature sea lampreys.

Sea lamprey depredations in Lakes Huron and Michigan had all but eliminated lake trout, *Salvelinus namaycush*, from these waters (Hile, 1949; Hile, Eschmeyer, and Lunger, 1951) by 1950. Lake Superior contained the only remaining stocks of this valuable commercial and game species. The rapidity with which lake trout populations had been destroyed in the two lower lakes warranted the immediate use of any promising method of suppressing numbers of sea lampreys in Lake Superior. A program was initiated, therefore, during the spring of 1953 in streams tributary to Lake Superior to test the practicability of electric barriers as a means of control. The 1953-54 operations have been reported by Erkkila, Smith and McLain (1956). A review of this early work and the operation of the barriers from 1955 through 1960 is presented here. At the end of the 1960 season the use of barriers for experimental control ended. They now serve as monitoring devices to assess the effectiveness of chemical control.

History of the Program

Surveys were made of the physical characteristics of streams tributary to the U.S. waters of Lake Superior in 1950-52 (Loeb and Hall, 1952; Loeb, 1953). This work provided information on streams having habitat suitable for sea lamprey reproduction. The surveys also indicated that sea lamprey runs at that time were confined chiefly to streams entering the eastern part of Lake Superior. The first electric barriers, therefore, were built in this area.

Plans for the 1953 program called for the installation and operation of devices on 23 streams which were selected to provide diversity of stream characteristics, to cover an area sufficient to acquaint the staff with problems of servicing, and to include streams actually used by sea lampreys. Acquisition of land easements and leases caused so much delay that only

10 of the proposed units were ready for operation at the start of the 1953 spawning season. Construction of the other barriers continued, and although 9 more were completed by June 1, they were not operated that year.

The number of electric barriers was expanded in 1954 to 44, extending from the Waiska River at the eastern end of the lake, to the Union River a few miles west of Ontonagon, Michigan. This stretch of some 500 miles of Lake Superior's south shore has approximately 300 tributaries, including man-made ditches and wet-season drainages, about 145 of which were considered as possibly usable by spawning sea lampreys. The 44 streams selected for barriers were known to have, or were believed most likely to have sea lamprey runs.

During the 1954 season, no sea lampreys were caught at 18 of the 44 control devices. Rather than continue the installation of barriers on all potential spawning streams, it appeared more practical to operate them only on those streams in which sea lamprey runs existed. Ten of the 18 "unproductive" barriers were placed on standby. Control structures were installed on 2 new streams in which spawning was discovered. A total of 36 barriers was operated in 1955.

Toward the end of 1955, a study of the effects of temperature on embryological development showed that under constant temperatures no live larvae were produced below 60° F. or above 70° F. (Piavis, 1961). This knowledge contributed to a decision to place additional barriers on standby.

The 1956 barriers numbered 34. Sea lampreys were found in 3 new streams and 4 more "unproductive" units were placed on standby. Two of the new structures extended the operation west to Ashland County, Wisconsin.

The 1957 barrier system comprised 39 structures including an experimental direct-current device which was tested in the Brule River, Wisconsin. The number of barriers was increased to 45 for the 1958 season. Five of these units were temporary installations to check streams where results from previous attempts to determine the status of sea lamprey runs were considered unreliable.

The first field applications of selective larvicides were made during the 1958 season (Applegate, Howell, Moffett, Johnson, and Smith, 1961). The promise of a more immediate and effective method of control ended further construction of electric barriers. Installation of new structures was halted and repairs and modifications to existing structures were curtailed. Forty electric barriers were operated in 1959 and 37 in 1960. The 3 devices that were discontinued formed a group serviced by

one crew. Their elimination reduced personnel costs and made more money available for chemical control. The experiment to control sea lampreys with electric barriers ended in 1960.

Electric Barriers and Traps

Development of the electric barriers

The original electric devices were of the 3 basic types described by Erkkila, Smith, and McLain (1956). Basically, they consisted of an electrode array across a stream to establish an electric field from one bank to the other. A trap with leads or wings was installed at each barrier. The 3 types differed as to the electrode arrangement. The first, which consisted of 2 parallel rows of hanging electrodes suspended across the stream by catenary cables, was designed for the deeper streams. The second had a single row of suspended electrodes and a submerged electrode on the bottom parallel to the suspended electrodes. These barriers were installed in streams of medium depth. The third, consisting of 2 submerged electrodes lying parallel across a streambed, was restriced to shallow waters.

Traps were installed with the wings or leads terminating at the downstream fringe of the electric field. It was believed that many fish migrating upstream would be diverted by the fringe of the electric field and, in their search for a passage, would enter the trap. Thus, the traps interrupted the electric fields and served as part of the barrier in the early structures. The ability of the sea lamprey to withstand a relatively severe electric shock without apparent physical harm and their persistence frequently enabled them to find any passage which existed or developed under or around the traps. By 1956, most barriers were modified to establish an uninterrupted field from one bank to the other. The traps were installed downstream from the electric field, usually adjacent to a stream bank.

Experience led to further modifications. Only 3 barriers were installed with the double row of suspended electrodes. These structures lacked the flexibility required for alteration of electrode spacing and surface area to provide the field intensity required by the low electrical conductivities of water in Lake Superior tributaries.

New installations or modifications to existing barriers were

based on the design with a single row of suspended electrodes or on the shallow-water type. Each device was built to meet the electrical and physical characteristics of the particular stream.

The electrode arrays were energized with 115-volt alternating current. Some of the largest and most complex barriers used multiple 115-volt fields. The scope of the program made the use of alternating current mandatory. Cost was important as was simplicity which increased reliability, reduced maintenance, and eased the burden of training a comparatively large staff.

Generators supplied the alternating current where commercial power was not available. Auxiliary power plants were maintained at all sites to provide power automatically should the main source fail. A small building housed the generators, control panels, switch boxes, and spare parts.

Many modifications or innovations were incorporated to increase the efficiency of the structures but they did not materially influence the electric fields. Changes and additions included: the installation of wood or concrete abutments which served to channel the stream flow and increase water velocity; enlarged traps; and bottom stabilization. The improvements reduced mortality of fish and increased the ability of the barriers to capture desirable migrants to be moved upstream.

The abutments also provided a secure mounting for traps and facilitated installation and servicing of larger traps under adverse stream conditions. The traps were successively enlarged and improved. Several installations had compartmented traps with multiple-funnel arrangements to increase trapping and holding efficiency.

Each control device was completely enclosed by a fence and posted to warn the public. A red light also was installed as a warning signal. Safety switches were placed at each installation and were manned during servicing. In addition, fishing was prohibited in the immediate vicinity of the electric barriers.

Electric fields

The effectiveness of each structure depended upon the ability of its electric field to immobilize all adult sea lampreys. The intensity of the field had to be great enough to induce paralysis regardless of the orientation of the animal's body to the lines of current flow. The effective field also had to be sufficiently deep to prohibit the momentum of a rapidly swim-

ming sea lamprey from carrying the stunned animal completely through the barrier. These conditions had to be maintained throughout the operational period during which physical and electrical characteristics of the stream varied widely.

The most difficult period through which to maintain an effective field was early spring when the water was high, temperatures were low, and water conductivities were at the minimum. The problem was made more troublesome by the lack of reliable criteria or standards upon which to base the strength of the electric fields. Originally we believed that we could use an earlier comprehensive series of voltage-gradient measurements from electric fields established in streams tributary to northern Lakes Huron and Michigan (Applegate, Smith, and Nielsen, 1952). This series indicated that a minimum gradient of 0.75 volt per inch must exist to block the sea lamprey run completely. A voltage gradient of at least 1.00 volt per inch was recommended to provide a margin of safety. This standard was adopted during the early years of operation on Lake Superior. Unfortunately, the escapement that occurred during 1953 and 1954 was the result of mechanical failures. Not until later was it discovered that a field with a voltage gradient of 1.00 volt per inch was not sufficiently intense to block all sea lampreys during the periods of low water conductivities on some Lake Superior streams. The problem was brought out even more sharply by work on the Canadian side of Lake Superior (Lawrie, 1959). Electric barriers based on the specifications of those used in U.S. waters were partially ineffective due to low water conductivities (Lenson and Lawrie, 1959).

The combined effect of water conductivity and voltage gradient on the reaction of a fish has long been recognized. McMillan (1928) demonstrated that a much higher voltage gradient was required to paralyze a fish in water of low conductivity than in conductive water. Other investigators have discussed the relation of the resistivity of the body of a fish to that of the water. Among them are: Haskell, 1954; Whitney and Pierce, 1957; Meyer-Waarden, 1957; and Rollefson, 1958. Despite these studies, no reliable standards existed on which the intensity of the electric field could be based to assure a complete block of all sea lampreys at minimum water conductivities. It was undesirable to increase field intensity indiscriminately at all barriers since it was necessary to keep mortality of other fish low.

An extensive series of conductivity measures[1] obtained after 1954 to provide a background for establishing the intensity of the electric fields, led to maintenance of more intense fields in streams with relatively low water conductivity. McCauley (1960) published data on the relationship between water conductivity and the voltage gradient required to paralyze a sea lamprey. McCauley demonstrated that the relation is not linear and that below 100 micromhos the critical gradient becomes markedly dependent on water conductivity. This finding provided a more reliable criterion on which to base field intensity.

Direct-current diversion devices

Mortality of fishes was considerable at some of the early electric barriers (Erkkila, Smith, and McLain, 1956). During 1956, 2 direct-current diversion devices were tested in conjunction with the alternating-current barriers in an attempt to reduce fish mortality and increase trapping efficiency. The diversion devices, described in detail by McLain (1957), were successful. The experimental models used interrupted direct current at a duty cycle of 0.66 and a repetition rate of 3 pulses per second. The wave shape of the pulses was essentially square.

The experimental equipment to provide the interrupted direct current proved unsatisfactory for prolonged, uninterrupted use. This equipment was replaced by one of two types of direct-current relaxing pulse generators.[2] One type produced unfiltered, half-wave, rectified alternating current and the other had an output of unfiltered, full-wave, rectified alternating current.

Half-wave, rectified alternating current was tested during 1952 (McLain and Nielsen, 1953) and both full- and half-wave, rectified alternating currents were tried during 1954. The galvanotactic response to either type of current is not as satisfactory as that elicited by square-wave pulses of direct current. The scope of the program, economic considerations, and other factors made it desirable, nevertheless, to use the output of the relaxing pulse generators.

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[1] Conductivity measurements were taken with a conductivity bridge, Industrial Instruments, Inc., Model RC - 16B - 1.

[2] Designed and constructed by Mr. George Belprez, Walled Lake, Michigan.

Seven diversion devices, including the 2 experimental models, were operated during 1957 in conjunction with alternating-current barriers. Eventually 12 of these devices were in operation in tributaries to Lake Superior where the destruction of fish by the alternating-current fields had become a problem.[3]

Experience in the operation of the diversion devices led to no major change from the basic principles. Several improvements in the installation and in design were developed, however. The single structure that deviated from the basic design was installed with its electrode array in the form of a "V" with the apex downstream. Located in the Brule River, Wisconsin, it was one of the most efficient of the diversion barriers.

Operation of the Control Barriers

The experimental electric barriers finally extended along the south shore of Lake Superior from Sault Ste. Marie, Michigan, to Superior, Wisconsin. This distance was divided into 11 control zones designated as S-1 to S-11 from east to west (Fig. 1). Each zone, with the exception of S-8, contained from 3 to 8 control devices which could be serviced daily by 1 crew (Table 1). No runs of sea lampreys developed in streams of control zone S-8.

No barriers were installed in streams along the Minnesota shore. The Pigeon River which forms the border between the State of Minnesota and the Province of Ontario had the only known sea lamprey run. Sea lampreys spawned occasionally in several Minnesota streams but no ammocetes were established in these streams.

A 3-man crew was assigned to each control zone. The men worked a 5-day week on a staggered basis so that 2 men were on duty each day. They were responsible for servicing each electric barrier once daily.

Fish and sea lampreys were removed from the traps and the fish were released, those killed by the electric field were

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[3] Some of the later structures were energized with the output of direct-current relaxing pulse generators, Model 30-B, manufactured according to our specifications by the Electric Fish Screen Company, Hollywood, California.

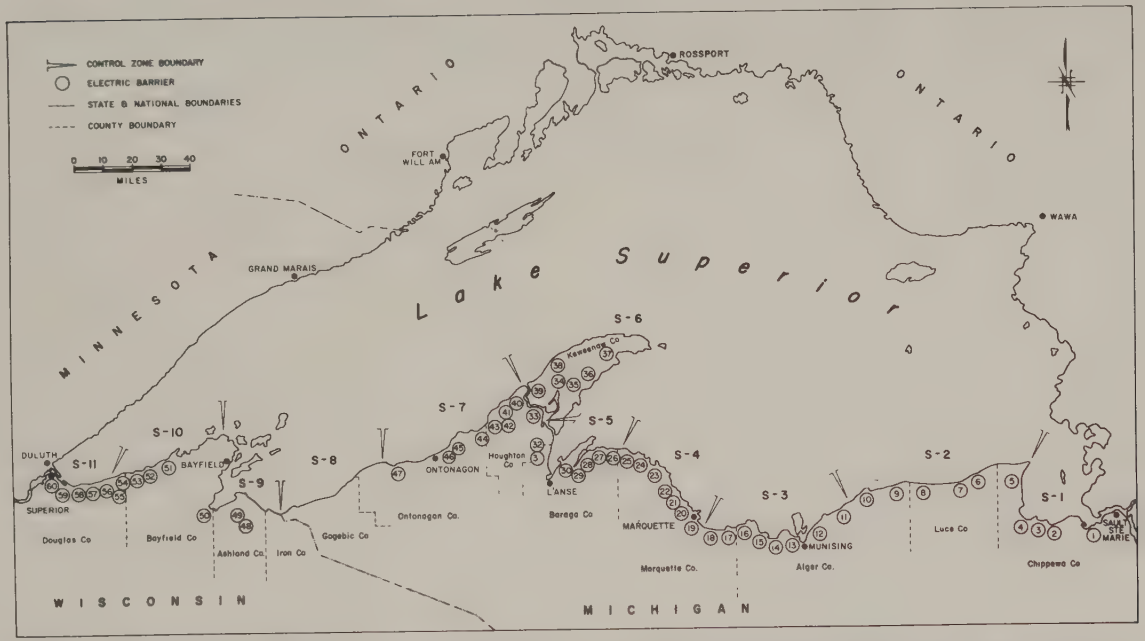

Figure 1.--Map of Lake Superior showing boundaries of control zones and the location of all electric barriers. The numbers on the map correspond to the numbers assigned to individual streams listed in Table 1.

Table 1.—Control zones and streams tributary to Lake Superior in which electric barriers were installed and the years of operation

[The number assigned to each stream is the barrier number in Figure 1.]

Control zone and stream	Years of barrier operation
Zone S-1	
1. Waiska River	1954-60
2. Pendills Creek	1953-60
3. Halfaday Creek	1954-58
4. Ankodosh Creek	1954
5. Betsy River	1953-60
Zone S-2	
6. Little Two Hearted River	1957-60
7. Two Hearted River	1953-60
8. Dead Sucker River	1953-54
9. Sucker River	1953-60
10. Hurricane River	1954-60
Zone S-3	
11. Beaver Lake Outlet	1953-58
12. Miners River	1953-60
13. Furnace Creek	1953-60
14. Au Train River	1953-60
15. Rock River	1955-60
16. Laughing Whitefish River	1953-60
17. Sand River	1954
18. Chocolay River	1954-60
Zone S-4	
19. Carp River	1954-60
20. Harlow Creek	1954-60
21. Little Garlic River	1954-55
22. Big Garlic River	1954-60
23. Iron River	1954-60
24. Salmon Trout River	1954-56; 1959-60
25. Pine River	1954-60
Zone S-5	
26. Little Huron River	1954
27. Huron River	1954-60
28. Ravine River	1954-60
29. Slate River	1954
30. Silver River	1954-60
31. Sturgeon River	1954-60
32. Otter River	1954-58

Table 1.—Continued

Control zone and stream	Years of barrier operation
Zone S-6	
33. Pilgrim River	1954
34. Traprock River	1954-55
35. Traverse River	1954-59
36. Tobacco River	1954
37. Little Gratiot River	1954-59
38. Gratiot River	1954-59
39. Boston and Lily Creek	1954
40. Schlotz Creek	1954
Zone S-7	
41. Graveraet River	1954
42. Elm River	1954-60
43. South Branch Elm River	1954-55
44. Misery River	1955-60
45. Firesteel River	1954-60
46. Flintsteel River	1954-60
47. Union River	1954-55
Zone S-8	
Zone S-9	
48. Bad River	1956-59
49. White River	1956-60
50. Fish Creek (Eileen Township)	1957-60
Zone S-10	
51. Cranberry River	1958-60
52. Iron River	1958
53. Reefer Creek	1958
54. Fish Creek (Orienta Township)	1958
55. Brule River	1957-60
Zone S-11	
56. Poplar River	1957-60
57. Middle River	1957-60
58. Amnicon River	1957-60
59. Black River	1958-60
60. Nemadjii River	1958-60

collected, and the numbers and species recorded. Water temperature, water level, weather, power consumption, and other data were recorded. The crews maintained and repaired all barrier components.

At least 1 river in each control zone was designated as an "index" stream in which sex, weight, and length were deter-

mined for individuals in samples from the daily catch of sea lampreys.

The work load diminished as fish runs declined. It then became the duty of the service crews to check for sea lamprey escapement and for any indication of sea lamprey spawning in uncontrolled streams in their zones.

Sea Lamprey Catch

1953 season

The 10 electromechanical weirs operated in 1953 captured or killed 1,668 adult sea lampreys. Only 1 device, on the Dead Sucker River, failed to take lampreys.

1954 season

The 44 units produced 4,922 sea lampreys, including 1,227 from a mechanical weir which had been installed in the Chocolay River, near Marquette, Michigan. The catch for the 10 original devices increased to 3,048 individuals, nearly double that of the previous year. The 33 new electric barriers captured only 647, or 13.1 percent, of the total.

The capture of 4,327 of the 4,922 adults at the 17 barriers east of Marquette confirmed earlier indications that sea lampreys were concentrated in the eastern portion of Lake Superior. The 27 barriers west of Marquette captured 595 sea lampreys and 529 of these were taken east of the Keweenaw Pennisula. Eighteen of the 44 devices took no sea lampreys (14 of the 18 were west of Marquette).

1955 season

The number of barriers was reduced to 36 in 1955. Ten barriers, unproductive in 1954, were placed on standby and new barriers were installed on the Misery and Rock Rivers. The mechanical weir on the Chocolay River, which had allowed considerable escapement and had placed excessive demands on the staff for operation, was replaced by an electrical device.

The 36 barriers captured or killed 10,639 adult sea lampreys, more than double the number taken in 1954. The most significant increase was at structures west of Marquette. The

increase was threefold—from 595 in 1954 to 1,917 (including 183 adults from the new device on the Misery River) in 1955. The catch east of Marquette was 8,722 sea lampreys as compared to 4,327 in 1954, but 1,633 individuals from the new device on the Rock River made a significant contribution to the increase.

1956 season

Thirty-four electric barriers were operated in 1956. Four additional units were placed on standby and structures were installed on the Bad and White Rivers in Ashland County, Wisconsin.

The upward trend in numbers of adult sea lampreys continued in 1956. The barriers captured 24,084 individuals, again more than doubling the catch of the previous year. The new structures on the Bad and White Rivers took 685 and 219 lampreys, respectively.

1957 season

During the 1956 spawning season, sea lampreys were found in 5 more Wisconsin streams. Electrical devices were installed and readied for the 1957 season on 4 of them (Fish Creek, Bayfield County, and the Poplar, Middle, and Amnicon Rivers in Douglas County). A barrier was not completed on the fifth stream, Brule River, but an experimental direct-current diversion device was installed and operated from May 19 to July 18.

The barrier on the Salmon Trout River which had captured only 1 sea lamprey in 3 years was placed on standby. A new device constructed on the Little Two Hearted River increased the number of barriers to 39 including the experimental device on the Brule River.

The barriers took 57,820 adult sea lampreys in 1957 including 3,988 from the special unit on the Brule River. Again, the catch more than doubled that of the preceding year, but only because of the contribution of the new structures in Wisconsin streams. The 4 new units captured 15,990 adults. The combined production from Wisconsin streams totaled 23,042 sea lampreys, or nearly 40 percent of the entire catch.

Barriers along the eastern half of Lake Superior's shoreline, the area covered since 1954, produced 34,778 sea lampreys as compared with 23,200 in 1956. The numbers for the first

time failed to double; the increase was only about 50 percent over the preceding year.

Several major modifications were made to some of the barriers. Direct-current diversion equipment was installed and operated on the Two Hearted River, Sucker River, Beaver Lake Outlet, Chocolay River, Huron River, Silver River, Bad River, and Fish Creek. Major improvements were made to 6 barriers on other streams. The extent of increase in catch attributable to the improvements is not known.

1958 season

The control barriers were increased to 45 units for the 1958 season. A new device was installed on the Cranberry River, the Brule River structure was completed, and 5 structures were installed as checking devices to determine the status of streams in which the establishment of runs was questionable. Fifteen devices remained on standby.

The 45 electric barriers took 66,931 adult sea lampreys in 1958. Only 5 barriers failed to capture adults. The 32 barriers in Michigan waters accounted for 24,293 adults (36.3 percent) and those in Wisconsin took 42,638 (63.7 percent). Over 94 percent (62,890) of the lampreys were produced in 12 rivers. The Brule River alone accounted for 22,842 individuals, or 34.2 percent, of the total catch.

For the first time, the numbers of sea lampreys in streams tributary to the eastern half of Lake Superior were lower than in the preceding year. Previously, the catch from 19 eastern streams had nearly doubled each year since 1954 until 1957 when the increase was only 52.9 percent. In 1958, the number dropped to 19,509, a reduction of 31.9 percent as compared to the high of 28,642 adults in 1957 (Table 2).

The increase of 1958 (66,931) over the 1957 catch (57,820) may not reflect an actual increase in the population of adult sea lampreys. The catch on the Brule River in 1957 was made by the diversion device which was not designed to capture all sea lampreys and was not operated throughout the migratory period. Experienced observers estimated that numbers of sea lampreys in the Brule River greatly exceeded the 3,988 captured. Any number from the Brule in excess of 10,000 would have made the 1957 catch larger than that of 1958.

Table 2.--Total catches of sea lampreys from 19 streams of eastern Lake Superior that had control devices for 7 years, 1954-60

Stream	1954	1955	1956	1957	1958	1959	1960
Waiska River	32	47	71	55	70	43	127
Pendills Creek	40	45	42	47	17	40	33
Betsy River	567	569	1,577	786	1,092	1,006	705
Two Hearted River	638	600	1,766	7,899	3,577	4,141	4,508
Sucker River	1,309	1,713	4,400	3,597	1,842	2,522	4,980
Hurricane River	8	25	99	183	29	65	80
Miners River	53	148	96	427	97	159	411
Furnace Creek	47	66	209	274	41	396	2,293
Au Train River	350	486	613	739	348	168	80
Laughing Whitefish River	25	16	19	37	11	28	42
Chocolay River	1,227	3,350	6,888	8,096	6,221	3,500	4,216
Carp River	0	2	1	4	0	5	5
Harlow Creek	1	1	0	3	3	31	14
Iron River	67	206	335	737	428	266	342
Pine River	10	12	18	34	22	43	28
Huron River	147	472	1,628	2,868	3,526	1,492	1,377
Ravine River	1	4	2	10	5	23	8
Silver River	247	786	963	2,810	2,152	878	1,386
Sturgeon River	1	1	4	31	28	544	161
Total	4,770	8,549	18,731	28,642	19,509	15,350	20,796
Percentage change	...	79.2	119.1	52.9	-31.9	-21.5	35.5

1959 season

The successful field trials during 1958 with selective larvicides for the control of the sea lampreys ended further expansion of the electric barrier program. Plans for the construction of new devices were abandoned. The number of barriers was reduced from 45 to 40 for the 1959 season. Detection of sea lampreys in the Salmon Trout River led to re-activation of its barrier, which had been on standby since 1956.

The 40 barriers captured 52,173 sea lampreys during the 1959 season, a reduction of 22.0 percent from the 1958 catch.

Table 3.—Total catches of sea lampreys from 11 streams of western Lake Superior that had control devices for 3 years, 1958-60

Stream	1958	1959	1960
Elm River	2	8	12
Misery River	896	2,581	761
Firesteel River	1,546	2,084	276
Flintsteel River	2	0	0
White River	231	552	233
Fish Creek	251	428	354
Cranberry River	0	14	50
Brule River	22,842	19,389	9,755
Poplar River	580	8	58
Middle River	4,853	3,645	2,839
Amnicon River	7,670	986	1,165
Total	38,873	29,695	15,503
Percentage change	. . .	-23.6	-47.8

For the second consecutive year, the numbers of sea lampreys decreased in streams tributary to the eastern part of Lake Superior. The reduction of 31.9 percent in 1958 was followed by a 21.5-percent drop in 1959 (Table 2). The total catch of adults decreased also in streams tributary to the western half of Lake Superior. Streams west of the Keweenaw Peninsula produced 29,695 individuals as compared to 38,873 in 1958 (Table 3).[4]

Again, over 90 percent of the adults were taken from 12 streams. The Brule River accounted for 19,389, or 37.2 percent, of the season's catch. The 30 barriers operated in Michigan waters produced 22,669 (43.4 percent) and those in Wisconsin captured 29,504 (56.6 percent) of the sea lampreys.

1960 season

A total of 37 electric barriers was placed in operation for the 1960 season. Their effectiveness was greatly lessened in

[4] Comparisons of seasonal catches are based on only those streams in which the operation of barriers was not interrupted.

early season by unprecedented floods. Several traps were inundated for periods up to 30 days. The Bad River barrier, one of the largest and most complex structures, suffered such serious damage that it was abandoned.

A second barrier, Big Garlic River, was removed because of the need for a complete re-installation. Thus, only 35 electric barriers actually operated through the 1960 season.

The catch of sea lampreys was 39,783 during the 1960 season.[5] After two consecutive years of decline, the catch from 19 streams in the eastern half of Lake Superior increased. These streams produced 20,796 adults as compared to 19,509 and 15,350 in 1958 and 1959, respectively (Table 2). This increase was more than compensated by a drop in the numbers of adults in the western streams. The total catch from 11 western streams dropped from 29,695 in 1959 to 15,503 in 1960, a reduction of 47.8 percent (Table 3).

Over 90 percent of the sea lampreys caught in 1960 were taken from 11 streams; the Brule River alone accounted for 24.5 percent of the catch. The Flintsteel River was the only stream that did not produce a sea lamprey. Most unusual among the runs during 1960 was at Furnace Creek, a small stream in Alger County, Michigan. It produced 2,293 adults as compared to its highest previous record of 396 in 1959.

Summary for 1953-60

Beyond the initial increase in the numbers of sea lampreys during the first few years, the runs showed few trends (Table 4). The most easterly of the streams, those in control zone S-1, appeared to have reached their peak production in 1956. Streams in control zones S-2 to S-5 yielded their greatest catches in 1957, and by 1958, the peak was reached in the western rivers. Subsequent fluctuations in numbers are unexplained but may reflect a normal variation in the size of the population as it became established. Since no definite conclusion has been reached relative to the duration of the larval stage, it is difficult to speculate as to whether the barriers had been operated on enough streams and for a long enough time to have contributed to the indicated drop in population levels in 1959 and 1960.

[5] Including 87 sea lampreys taken by the Big Garlic weir prior to its removal on May 29.

Table 4.—Catches of sea lampreys by control zone and stream for all electric barriers operated in U.S. tributaries to Lake Superior, 1953-60

Control zone and stream	1953	1954	1955	1956	1957	1958	1959	1960
Zone S-1								
Waiska River	...	32	47	71	55	70	43	127
Pendills Creek	23	40	45	42	47	17	40	33
Halfaday Creek	...	12	3	14	4	2	...	...
Ankodosh Creek	...	0	...	...	...	...	...	...
Betsy River	221	567	569	1,577	786	1,092	1,006	705
Zone total	244	651	664	1,704	892	1,181	1,089	865
Zone S-2								
Little Two Hearted River	...	...	...	...	739	460	461	715
Two Hearted River	371	638	600	1,766	7,899	3,577	4,141	4,508
Dead Sucker River	0	0	...	...	...	...	...	...
Sucker River	750	1,309	1,713	4,400	3,597	1,842	2,522	4,980
Hurricane River	...	8	25	99	188	29	65	80
Zone total	1,121	1,955	2,338	6,265	12,423	5,908	7,189	10,283
Zone S-3								
Beaver Lake Outlet	8	19	19	20	49	18	...	...
Miners River	64	53	148	96	427	97	159	411
Furnace Creek	18	47	66	209	274	41	396	2,293
Au Train River	204	350	486	613	739	348	168	80
Rock River	...	...	1,633	3,407	3,102	1,488	1,250	2,646
Laughing Whitefish River	9	25	16	19	37	11	28	42
Sand River	...	0	...	...	...	...	...	...
Chocolay River	...	1,227	3,350	6,888	8,096	6,221	3,500	4,216
Zone total	303	1,721	5,718	11,252	12,724	8,224	5,501	9.688

Table 4.—Continued

Control zone and stream	1953	1954	1955	1956	1957	1958	1959	1960
Zone S-4								
Carp River	...	0	2	1	4	0	5	5
Harlow Creek	...	1	1	0	3	3	31	14
Little Garlic River	...	0	0	...	...	...	...	...
Big Garlic River	...	54	89	154	270	262	247	87[1]
Iron River	...	67	206	335	737	428	266	342
Salmon Trout River	...	1	0	0	...	...	68	5
Pine River		10	12	18	34	22	43	28
Zone total	...	133	310	508	1,048	715	660	481
Zone S-5	...							
Little Huron River	...	0	...	...	...	...	...	...
Huron River	...	147	472	1,628	2,868	3,526	1,492	1,377
Ravine River	...	1	4	2	10	5	23	8
Slate River	...	0	...	...	...	...	...	...
Silver River	...	247	786	963	2,810	2,152	878	1,386
Sturgeon River	...	1	1	4	31	28	544	161
Otter River		0	0	1	0	0	...	...
Zone total	...	396	1,263	2,598	5,719	5,711	2,937	2,932
Zone S-6	...							
Pilgrim River	...	0	...	...	...	...	...	...
Traprock River	...	0	0	...	...	...	...	...
Traverse River	...	3	4	37	45	76	598	...
Tobacco River	...	0	...	...	...	...	...	...
Little Gratiot River	...	0	1	4	9	1	11	...
Gratiot River	...	1	0	4	2	31	11	...

Table 4.—Continued

Control zone and stream	1953	1954	1955	1956	1957	1958	1959	1960
Zone S-6 Continued								
Boston and Lily Creek	...	0	...	...	...	...	...	...
Scholtz Creek	...	0	...	...	...	...	...	...
Zone total	...	4	5	45	56	108	620	...
Zone S-7								
Graveraet River	...	0	...	...	...	...	...	...
Elm River	...	0	7	7	7	2	8	12
South Branch Elm River	...	0	0	...	...	...	...	...
Misery River	...	...	183	571	868	896	2,581	761
Firesteel River	...	60	150	229	1,039	1,546	2,084	276
Flintsteel River	...	2	1	1	2	2	0	0
Union River	...	0	0	...	...	...	...	...
Zone total	...	62	341	808	1,916	2,446	4,673	1,049
Zone S-9								
Bad River	...	...	...	685	2,652	6,203	4,468	...
White River	...	...	...	219	412	231	552	233
Fish Creek	...	...	...	...	520	251	428	354
Zone total	...	...	...	904	3,584	6,685	5,448	587
Zone S-10								
Cranberry River	...	...	...	...	...	0	14	50
Iron River	...	...	...	...	...	0	...	...
Fish Creek	...	...	...	...	...	0	...	...
Reefer Creek	...	...	...	...	...	1	...	...
Brule River	...	...	...	...	3,988[2]	22,842	19,389	9,755
Zone total	...	...	...	...	3,988	22,843	19,403	9,805

Table 4.—Continued

Control zone and stream	1953	1954	1955	1956	1957	1958	1959	1960
Zone S-11								
Poplar River	...	...	...	...	126	580	8	58
Middle River	...	...	...	...	4,289	4,853	3,645	2,839
Amnicon River	...	...	...	...	11,055	7,670	986	1,165
Black River	...	...	...	...	...	4	13	21
Nemadji River	...	...	...	...	...	3	1	10
Zone total	...	...[2]	...	...	15,470	13,110	4,653	4,093
Total	1,668	4,922	10,639	24,084	57,820	66,931	52,173	39,783

[1] Operation terminated May 29.

[2] Catch from experimental device operated from May 19 to July 18, not indicative of total run.

Table 5.--Sea lamprey catch by 5-day periods expressed as percentage of total run, 1953-60

Period	1953	1954	1955	1956	1957	1958	1959	1960
March 22-26	...	0.00	0.02	0.05	0.00	0.00[1]	0.00	0.00
March 27-31	...	0.02	0.04	0.03	0.00	0.02	0.02	0.00
April 1-5	0.00	0.00	0.09	0.10	0.01	0.11	0.44	0.01
April 6-10	0.06	0.06	0.05	0.02	0.14	1.09	0.42	0.11
April 11-15	0.06	0.21	0.08	0.34	0.15	0.99	0.90	0.22
April 16-20	0.06	0.10	0.25	0.31	0.19	2.06	0.15	0.25
April 21-25	0.84	0.76	0.97	0.54	0.74	3.02	0.63	0.64
April 26-30	0.30	0.84	9.33	0.54	3.38	1.62	0.98	0.69
May 1-5	2.70	4.42	13.13	0.76	5.83	4.30	8.66	1.14
May 6-10	14.69	1.25	2.24	3.84	12.86	6.09	8.94	1.19
May 11-15	11.15	11.89	6.02	6.87	5.63	18.98	8.58	3.02
May 16-20	10.13	6.63	5.76	3.34	3.23	9.01	6.81	9.84
May 21-25	7.61	11.26	10.42	8.82	11.55	8.16	5.40	10.39
May 26-30	5.58	3.74	3.48	11.07	10.05	7.22	12.88	9.57
May 31-June 4	8.57	3.06	7.02	7.40	12.84	4.04	10.53	9.38
June 5-9	12.59	17.99	8.53	15.05	5.75	11.06	15.20	9.91
June 10-14	11.45	9.28	3.01	16.46	8.85	5.31	6.21	8.70
June 15-19	10.07	9.20	10.95	4.08	6.16	5.83	3.59	7.13
June 20-24	1.08	5.32	6.45	5.23	3.98	3.03	1.84	6.57
June 25-29	0.24	6.22	5.08	1.83	2.19	2.76	1.88	9.08
June 30-July 4	0.48	2.55	2.97	2.92	2.17	1.39	1.76	3.15
July 5-9	0.42	1.79	1.53	1.83	1.19	0.96	1.26	2.80
July 10-14	1.26	1.32	0.89	2.84	0.45	1.13	0.90	2.12
July 15-19	0.42	0.72	0.70	1.57	1.37	0.63	0.84	1.11
July 20-24	0.12	0.64	0.41	0.89	0.32	0.50	0.34	0.99
July 25-29	0.12	0.37	0.30	1.02	0.34	0.27	0.25	0.78
July 30-Aug. 3	0.00	0.14	0.08	0.69	0.18	0.14	0.20	0.50
Aug. 4-8	...	0.08	0.09	0.62	0.15	0.11	0.11	0.27
Aug. 9-13	...	0.12	0.05	0.60	0.10	0.06	0.10	0.17
Aug. 14-18	...	0.02	0.06	0.23	0.07	0.04	0.06	0.15
Aug. 19-23	...	...	0.00	0.07	0.07	0.04	0.06	0.08
Aug. 24-28	...	...	...	0.04	0.02	0.02	0.03	0.03
Aug. 29-Sept. 2	...	...	...	0.00	0.01	0.01	0.02	0.01
Sept. 3-7	...	...	...	0.00[1]	0.01	0.00[1]	0.00[1]	...
Sept. 8-12	...	...	...	0.00	0.02	0.00	0.01	...
Sept. 13-17	...	...	...	...	0.00[1]	...	0.00	...

[1] Less than 0.005.

Biology of Sea Lamprey Spawning Runs in Lake Superior

Time of migration

The catches at experimental barriers along the south shore of Lake Superior provided considerable information on the sea

lamprey spwaning migration. Conclusions presented by Applegate (1950) on timing of runs in tributaries to northern Lake Huron are in general agreement with those reached for Lake Superior except for differences attributable to the colder climate in the Superior area. Applegate stated, ". . .water temperature is the best guide as to when migratory activity will begin as well as to fluctuations in its intensity once it has started."

A few sea lampreys, although sporadic in their appearance at the barriers, can be expected as the mean daily water temperatures in streams reach and exceed 40° F. Upstream movement increases considerably after 50° F. is reached, generally during the first or second week of May (Smith, 1962). The intensity of the runs frequently fluctuates during this early period when water temperature and weather generally are variable. Once the waters exceed, and remain above, 50° F., the spawning runs become well established. They usually reach their peak by the end of May or during the first half of June (Table 5).

The runs slowly diminish through the last half of June, and by the end of the first week in July, over 90 percent of the migrants have entered the streams. The termination of the run is not abrupt. Although the numbers are small, almost daily catches can be expected from the larger streams through mid-August. By the end of August, only an occasional straggler appears at the barriers.

The operation of the barriers was generally terminated by the end of August, with the exception of those few streams in which late stragglers were most common. On occasion, individual barriers have been operated until September 19. The latest capture of a sea lamprey at a control device was on September 15.

The use of electric barriers as a method of control calls for awareness of the possible significance of those few individuals within a population that deviate from the rather well defined migratory behavior of the majority. Throughout the period of study, adult sea lampreys have been taken by experimental devices, nets, larvicide, or have been observed in some Lake Superior stream nearly every month of the year.

It was believed originally that sea lampreys entered the mouths of rivers with deep estuaries well in advance of any warming of the river waters, but that their upstream penetration was limited. The number and geographic distribution of the barriers demanded that the devices be activated at the earliest possible time because the period between ice break-up and a temperature rise in stream waters can be exceedingly

Table 6.--Average lengths (inches) and weights (ounces) of sea lampreys (sexes combined) from index streams of Lake Superior, 1953-60

Stream	1953	1954	1955	1956	1957	1958	1959	1960
Betsy River								
Length	...	18.3	17.7	18.0	17.0	16.6	17.0	16.6
Weight	...	...	7.4	7.3	5.7	5.6	6.3	5.5
Sucker River								
Length	...	18.0	17.0	17.7	16.8	16.6	16.8	16.4
Weight	...	8.0	6.9	7.3	5.6	5.5	5.8	4.9
Au Train River								
Length	17.8	17.7	17.0	17.9	17.1	16.6	17.1	16.5
Weight	...	7.5	6.5	8.0	6.5	5.8	5.9	5.5
Chocolay River								
Length	...	18.1	17.2	18.0	17.0	16.5	16.9	16.2
Weight	8.0	8.0	6.7	7.1	5.9	5.6	6.0	5.0
Iron River								
Length	...	17.8	16.5	17.6	16.7	15.9	16.4	16.1
Weight	...	8.0	6.0	6.8	6.0	5.5	6.2	5.3
Silver River								
Length	...	17.9	17.4	17.5	16.7	16.7	16.3	16.1
Weight	...	8.1	7.2	6.6	6.1	5.5	5.7	5.1
Misery River								
Length	...	...	...	...	...	...	...	17.4
Weight	...	...	...	...	...	...	...	5.3
Firesteel River								
Length	...	17.9	17.5	17.5	17.1	16.6	17.6	16.8
Weight	...	7.9	6.8	6.8	6.1	5.3	6.0	5.1
White River								
Length	...	...	...	18.1	17.0	16.6	16.9	16.1
Weight	...	...	...	7.1	5.7	5.5	5.9	5.0
Brule River								
Length	...	...	...	...	...	16.9	16.9	16.3
Weight	...	...	...	...	...	6.1	5.9	5.4
Middle River								
Length	...	...	...	...	...	...	...	16.6
Weight	...	...	...	...	...	...	...	5.4
Amnicon River								
Length	...	...	...	...	17.4	17.2	16.7	16.6
Weight	...	...	...	...	6.6	6.1	5.8	5.3
Length all streams								
Inches	17.8	18.1	17.2	17.8	17.0	16.8	16.9	16.4
Millimeters	452	460	437	452	432	427	429	417
Weight all streams								
Ounces	8.0	8.0	6.9	7.2	6.2	5.8	5.9	5.2
Grams	227	227	196	204	175	165	167	148

short. It became routine to install electrodes where practical by cutting openings in the ice. This procedure revealed that sea lampreys, although not numerous, did move considerable

distances up some rivers at low water temperatures.

The Huron River device, located approximately 3 stream miles above the mouth, captured 3 adult sea lampreys in 1957 while the river was still ice-covered and the maximum recorded temperature was 33° F. In 1958, 8 adults were taken before the mean daily temperature had exceeded 35° F., and in 1960, 10 were trapped before a mean daily temperature of 34° F. was surpassed. The Chocolay River structure, some 15 stream miles above the river's mouth, took 3 adults in 1957, 9 in 1958, and 2 in 1959 before the mean daily temperature exceeded 37° F.

Length and weight of spawning migrants

One tributary (or more) in each control zone was designated as an index stream. Individuals in the daily catch of sea lampreys, or a representative sample, from each index stream were weighed and measured, and the sex was determined.

Length, weight, and sex data for sea lampreys comprising spawning runs have been reported from populations in Lakes Huron, Michigan and Superior, and in Cayuga Lake (Applegate, 1950; Applegate and Smith, 1950; Applegate *et al.*, 1952; Erkkila *et al.*, 1956; and Wigley, 1959). It could be expected that the average size of lampreys in the relatively new population in Lake Superior would exceed that in the established populations of Lakes Huron and Michigan. It was expected further that as numbers increased, the decline of host fishes or increased competition would bring a decline in the size of sea lampreys. Erkkila *et al.* (1956) stated that as the population increases in Lake Superior, a reduction in their size should become apparent.

Sea lampreys weighed and measured from the catch at the barriers in 1954 had an average length of 18.1 inches (sexes combined) and a mean weight of 8.0 ounces (Table 6). Since 1954, the trend in size, as predicted, has been downward. The average length and weight of animals appearing at the barriers during 1955 were 17.2 inches and 6.9 ounces. Size increased in 1956 to 17.8 inches and 7.2 ounces, but it dropped again in 1957 to 17.0 inches and 6.2 ounces. The decrease of size was small in 1958—0.2 inch in average length and 0.4 ounce in weight (16.8 inches and 5.8 ounces). The change from 1958 to 1959 again was small, 0.1 inch in length and 0.1 ounce in average weight, but the downward trend reappeared in 1960 when as a group, the spawning run had the smallest individuals encountered during the operation of the experimental barriers. The average length and weight of sea lampreys from the 1960

spawning run were 16.4 inches and 5.2 ounces, 1.7 inches shorter and 2.8 ounces lighter than in 1954.

Sex was recorded for all sea lampreys that were weighed or measured. Differences in average length of males and females were not significant (Table 7). The average weight of females consistently exceeded that of males, but by only 0.1 to 0.2 ounce.

Sex ratio

The sex composition of upstream migrants captured at the electric barriers on index streams has been determined each season (Table 8). Erkkila *et al.* (1956) reported that the spawning run in 1953 included 49.7 percent males and that 58.3 percent were males in 1954.[6] During 5 of the 8 seasons (1954 and 1956-59), the sex composition remained almost constant;

[6] As actually reported the sex ratios were 99 males to 100 females in 1953 and 140 males to 100 females in 1954.

Table 7.--Average lengths and weights by sex of sea lampreys from index streams of Lake Superior, 1954-60

Year	Male			Female		
	Number	Inches and ounces	Millimeters and grams	Number	Inches and ounces	Millimeters and grams
1954						
Length	1,966	18.1	460	1,370	18.0	457
Weight	1,657	7.9	223	1,090	8.1	229
1955						
Length	3,282	17.2	437	2,892	17.3	439
Weight	3,282	6.9	196	2,892	7.0	198
1956						
Length	5,506	17.8	452	4,087	17.8	452
Weight	5,506	7.2	204	4,087	7.2	204
1957						
Length	6,345	17.0	432	4,670	17.1	434
Weight	6,345	6.1	172	4,670	6.3	178
1958						
Length	7,576	16.7	424	5,409	16.8	427
Weight	7,576	5.8	165	5,409	5.9	167
1959						
Length	8,826	16.9	429	6,216	16.9	429
Weight	8,826	5.9	167	6,216	6.0	169
1960						
Length	10,260	16.4	417	4,562	16.4	417
Weight	10,258	5.2	148	4,555	5.3	150

between 57.4 and 58.7 percent of the upstream migrants were males. The percentage of males dropped to 53.1 percent in 1955. The sex composition changed significantly in 1960 when the percentage of males increased to 69.2 percent.

Investigators have indicated that the trend toward an increasing porportion of males among mature sea lampreys may reflect a rising trend in the total population. Applegate (1950) stated that he did not believe a preponderance of males represents a natural sex ratio for the species and supported his contention by reporting a ratio of 79 males to 100 females (44.1 percent males) in a sample from the Sheepscot River in Maine. During 1950 and 1951, a mechanical weir with trap was operated in Pendills Creek, a tributary to Lake Superior (Applegate *et al.* 1952). The small sea lamprey runs (38 in 1950 and 20 in 1951) in this creek were comprised of 52.6 and 52.4 percent males for the 2 years. It was assumed this sex composition was indicative of a rather recently established population.

Sea lampreys in Cayuga Lake, New York, represent a long established fresh-water population. Wigley (1959) determined the sex composition of sea lampreys in the spawning migration in Cayuga Inlet, reviewed the findings of Meek (1889) and Surface (1899), and concluded the annual differences in the sex ratio do reflect changes in the abundance of sea lampreys.

Catches at the electric barriers give no indication of a close relation between sex ratio and abundance of sea lampreys in Lake Superior. The sex composition remained almost constant as the population increased sharply to 1958 and began to decline in 1959. Then in 1960, a further drop in the abundance of sea lampreys was accompanied by a significant increase in the preponderance of males.

Electric barriers also have been operated in streams entering Lake Michigan along its north and west shores. Males were consistently more plentiful than females in spawning runs of this established population. The percentage of males fluctuated from a low of 60.2 percent (1956) to a high of 69.1 percent (1957) from 1954 through 1960. The years with the highest and lowest percentage of males in the spawning runs were at the time when the catch at barriers indicated sea lampreys to be most abundant in Lake Michigan. The percentage of males increased from 1958 through 1960 while numbers of sea lampreys declined.

The causes of changes in the sex composition of the Lake Superior lamprey population are unknown. A preponderance of males conceivably may be characteristic of the species in a fresh-water environment.

Table 8.—Percentage of males from index streams on Lake Superior, 1953-60

[Number of sea lampreys in parentheses.]

Stream	1953	1954	1955	1956	1957	1958	1959	1960
Betsy River	50.3	52.2	55.6	58.8	58.5	59.0	56.7	65.9
	(221)	(567)	(569)	(1,577)	(786)	(1,092)	(1,006)	(705)
Sucker River	49.5	57.8	50.5	50.5	61.5	57.8	55.9	68.5
	(750)	(1,309)	(1,713)	(4,400)	(3,597)	(1,842)	(2,522)	(4,980)
Au Train River	56.1	56.3	53.3	64.8	58.2	51.7	64.4	68.4
	(204)	(350)	(486)	(613)	(739)	(348)	(168)	(80)
Chocolay River	. . .	66.8	54.8	59.5	57.4	55.2	56.1	72.2
	. . .	(1,227)	(3,350)	(6,888)	(8,096)	(6,221)	(3,500)	(4,216)
Iron River	. . .	57.8	56.7	57.3	55.8	52.4	58.3	72.5
	. . .	(67)	(206)	(335)	(737)	(428)	(266)	(342)
Silver River	. . .	51.0	51.9	52.8	52.6	53.1	54.1	64.9
	. . .	(247)	(786)	(963)	(2,810)	(2,152)	(878)	(1,386)
Misery River	. . .	. . .	. . .	. . .	. . .	. . .	. . .	70.1
	. . .	. . .	(183)	(571)	(868)	(896)	(2,581)	(761)
Firesteel River	. . .	54.3	49.2	48.5	52.6	53.9	62.3	60.8
	. . .	(60)	(150)	(229)	(1,039)	(1,546)	(2,084)	(276)

Table 8.—Continued

Stream	1953	1954	1955	1956	1957	1958	1959	1960
White River	. . .	. . .	. . .	54.5	55.2	63.5	65.8	69.1
	. . .	. . .	. . .	(219)	(412)	(231)	(552)	(233)
Brule River	. . .	. . .	. . .	. . .	. . .	60.5	61.1	70.8
	. . .	. . .	. . .	. . .	. . .	(22,842)	(19,389)	(9,755)
Middle River	. . .	. . .	. . .	. . .	. . .	. . .	. . .	68.8
	. . .	. . .	. . .	. . .	(4,289)	(4,853)	(3,645)	(2,839)
Amnicon River	. . .	. . .	. . .	. . .	59.8	61.4	55.9	65.8
	. . .	. . .	. . .	. . .	(11,055)	(7,670)	(986)	(1,165)
All streams	49.7	58.3	53.1	57.4	57.6	58.3	58.7	69.2

Species taken and their abundance

Large numbers of fish appeared at the barriers. Each individual entering the traps was identified and released. Those dead in the electric fields or below the weirs also were identified and removed. Before a list of names of the 62 species and a broad classification as to abundance is offered, certain factors affecting the catches should be reviewed briefly.

Principal factors in the numbers of each species taken at weirs were the actual abundance in the lake, the habitat preferences, and the migratory habits. Restricted geographic distribution along the lake shore influenced the catches of a few species and some fish that attain a small maximum size escaped the traps in large numbers. Examples of these influences illustrate the situation.

Such fish as bowfin and American eel are extremely scarce in Lake Superior and some species as lake sturgeon, muskellunge, carp, and largemouth bass, though taken more frequently, never appeared in large numbers. From these species that clearly are rare or uncommon, the gradation passes through such classifications as uncommon, common . . . to highly abundant.

Habitat preferences of different species limit the interpretation of catches at weirs in terms of true abundance. The most plentiful commercial species of Lake Superior, the lake herring, was rare in the catches and the widely distributed round whitefish was caught only sporadically. Other common to abundant fish were not taken and would not be expected at the barriers. Among them may be listed: lake whitefish *(Coregonus clupeaformis)*, deepwater ciscoes *(Coregonus* spp.), pygmy whitefish *(Prosopium coulteri)*, and fourhorn sculpin *(Myoxocephalus quadricornis)*. Catches of many, if not most, species at barriers were influenced in some measure by habitat preference but we are not in position to judge the effects accurately.

Species that moved upstream to spawn during the period of barrier operation were taken in substantial to enormous numbers. Among them may be mentioned smelt, longnose sucker, white sucker, trout-perch, rainbow trout, and, of course, the sea lamprey. If only part of the spawning period coincides with barrier operations (as with rainbow trout), the catch is reduced accordingly.

Among the fish that should have been caught in larger numbers except for restricted geographical distribution are American brook lamprey taken only in eastern Lake Superior and stonecat

and tadpole madtom captured only in Wisconsin streams.

Species that would have been captured in greater numbers except for their small size include many of the minnows, Iowa darter, Johnny darter, logperch, brook stickleback, and the two nonparasitic native lampreys.

Even though numbers taken at barriers cannot be interpreted closely in terms of the actual abundance of species some classification of fishes in terms of catch still seems desirable. The following listing of species is divided into broad categories ranging from "highly abundant" to "rare." The accompanying comments should aid in the understanding of the records.

Highly abundant - catch exceeded 10,000 for 1 or more seasons

American smelt *(Osmerus mordax)*	Caught in vast numbers, but rare or lacking in some streams.
Longnose sucker *(Catostomus catostomus)*	Widespread and extremely abundant; catches seriously limited by capacity of traps; immature fish absent except in the Brule River.
White sucker *(Catostomus commersoni)*	Widespread but less abundant than longnose suckers; catch also limited by capacity of traps; immature individuals common with spawning migrants.
Trout-perch *(Percopsis omiscomaycus)*	Widespread but numbers fluctuated widely; most abundant in streams of zones S-5, 6, and 7.
Sea lamprey *(Petromyzon marinus)*	The barrier operation covered a period during which the take of sea lampreys rose from less than 2,000 in 1953 to nearly 67,000 in 1958.

Abundant - catch exceeded 5,000 for 1 or more seasons

Common shiner *(Notropis cornutus)*	Widespread, but most abundant in western streams; common in the larger eastern streams.
Longnose dace *(Rhinichthys cataractae)*	Taken at all barriers; since they could not be retained easily by the traps, they probably were more abundant than catches indicated.

Logperch *(Percina caprodes)*	Widespread; this species also could not be retained efficiently by the traps.
Rainbow trout *(Salmo gairdneri)*	Widespread; classified as abundant when migratory adults are combined with young or immature fish; barrier operation did not cover entire migratory period; annual catch of spawning migrants varied from 1,500 to 2,200.
Lake chub *(Hybopsis plumbea)*	Uncommon in tributaries to eastern Lake Superior, but abundant in Wisconsin streams.
Brown bullhead *(Ictalurus nebulosus)*	Widespread; the catch fluctuated widely but the year-to-year trend was toward increased numbers and an increased number of streams.

Plentiful - catch exceeded 2,000 for 1 or more seasons

Mottled sculpin *(Cottus bairdi)*	Common throughout the area.
Silver lamprey *(Ichthyomyzon unicuspis)*	Widely distributed; not taken in large numbers at any 1 barrier.
Creek chub *(Semotilus atromaculatus)*	Present at most barriers, but greatest catches were from the larger streams.
Rock bass *(Ambloplites rupestris)*	Common to many streams throughout the area.
Brook trout *(Salvelinus fontinalis)*	Taken at nearly all barriers; most common in the catches from the Keweenaw Peninsula eastward.
Brown trout *(Salmo trutta)*	Recorded from many streams; most common in Wisconsin waters; strong spawning migration in the Brule River; seasonal termination of barrier operations coincident with beginning of run, possibly is the reason spawning runs were not detected in other streams.
Stonecat *(Noturus flavus)*	Catches restricted to barriers in Wisconsin streams.

Northern redhorse *(Moxostoma macrolepidotum)*	Limited to the larger rivers; generally deep and sluggish; majority of catch from the Bad and Sturgeon Rivers.

Common - catch exceeded 500 for 1 or more seasons

Northern brook lamprey *(Ichthyomyzon fossor)*	Not retained well by the traps; most abundant west of Marquette.
Black bullhead *(Ictalurus melas)*	Widespread; most common in streams of western Lake Superior.
Yellow perch *(Perca flavescens)*	Represented at many of the barriers; most numerous in streams with lakes in their systems.
Golden shiner *(Notemigonus crysoleucas)*	Scattered throughout the area covered by the barriers; largest catches at the Brule and Nemadji Rivers.
Burbot *(Lota lota)*	Widespread; catch consisted principally of small or immature fish.
Johnny darter *(Etheostoma nigrum)*	Common and undoubtedly abundant in most streams with barriers, but too small to be retained effectively by the traps.

Uncommon - catch less than 500 individuals per season

Brook stickleback *(Eucalia inconstans)*	Too small to be retained efficiently by the traps; taken in small numbers throughout the area.
American brook lamprey *(Lampetra lamottei)*	Too small to be retained effectively by the traps; recorded only at barriers of eastern Lake Superior.
Northern pike *(Esox lucius)*	Taken at most barriers, but not in large numbers.
Walleye *(Stizostedion vitreum vitreum)*	Caught in numbers comparable to northern pike, but at fewer barriers; generally from larger rivers.
Slimy sculpin *(Cottus cognatus)*	Widespread; most common in the colder streams.

Central mudminnow *(Umbra limi)*	Widespread; recorded at many of the barriers.
Hornyhead chub *(Hybopsis biguttata)*	Most common at barriers west of the Keweenaw Peninsula.
Smallmouth bass *(Micropterus dolomieui)*	Widely distributed; not taken in large numbers at any 1 barrier.

Sporadic - most of the catch at 1 or 2 barriers

Pumpkinseed *(Lepomis gibbosus)*	Taken in small numbers at several barriers, except for Chocolay River where catch has exceeded 5,000 in 1 season.
Round whitefish *(Prosopium cylindraceum)*	Up to 560 individuals from Two Hearted River in 1 season.
Black crappie *(Pomoxis nigromaculatus)*	Common in Sturgeon River up to 843 in 1 year; occasionally taken from 4 Wisconsin streams.
Spottail shiner *(Notropis hudsonius)*	Large catches from Beaver Lake Outlet.
Ninespine stickleback *(Pungitius pungitius)*	Taken in large numbers from 1 or 2 streams, but not every year.

Rare - annual catch varied from none to less than 60 per season

Bluegill *(Lepomis macrochirus)*	Five to 57 per season; widely distributed.
Northern redbelly dace *(Chrosomus eos)*	Maximum catch for 1 season was 55; recorded only from barriers on Michigan streams; too small to be retained well by the traps.
Silver redhorse *(Moxostoma anisurum)*	Recorded at the barriers in the larger deep, and sluggish rivers.
Blacknose dace *(Rhinichthys atratulus)*	Up to 54 recorded in 1 season; many undoubtedly escaped the traps.
Pearl dace *(Semotilus margarita)*	Too small to be retained efficiently by the traps; maximum number recorded for 1 season, 39.

Muskellunge *(Esox masquinongy)*	Maximum catch for 1 season, 35; confined principally to Wisconsin streams.
Alewife *(Alosa pseudoharengus)*	Rarely taken at the barriers although numbers appear to be increasing in Lake Superior; largest catch, 29 individuals from the Silver River in 1960.
Largemouth bass *(Micropterus salmoides)*	From 2 to 16 per season from scattered barriers.
Brassy minnow *(Hybognathus hankinsoni)*	Although reported throughout the area, taken only at barriers in Michigan waters.
Fathead minnow *(Pimephales promelas)*	Catch from none to 11 per season.
Finescale dace *(Chrosomus neogaeus)*	Although reported as present in Wisconsin streams, taken only from Michigan waters; maximum catch for 1 season, 10.
Tadpole madtom *(Noturus gyrinus)*	A maximum of 8 individuals for 1 season from barriers on 2 Wisconsin streams.
Emerald shiner *(Notropis atherinoides)*	Common along the shores of Lake Superior, but rarely taken; captured at only 3 barriers.
Carp *(Cyprinus carpio)*	Catch, none to 6 individuals per year; recorded from several streams throughout the area.
Lake herring *(Coregonus artedi)*	From 1 to 5 per year; generally from the larger rivers.
Iowa darter *(Etheostoma exile)*	From none to 5 per season from eastern barriers; too small to be retained effectively by the traps.
Blacknose shiner *(Notropis heterolepis)*	Maximum of 4 individuals in 1 season, but reportedly widespread; taken only from eastern streams.
Sand shiner *(Notropis stramineus)*	Maximum of 4 in 1 season.
Bluntnose minnow *(Pimephales notatus)*	Only an occasional specimen taken from the larger rivers.

Lake sturgeon *(Acipenser fulvescens)*	Relatively scarce in Lake Superior; taken in 2 streams; individuals also observed that were too large to enter the traps.
Lake trout *(Salvelinus namaycush)*	Small or immature fish taken from 2 streams, both of which have fish cultural stations.
Mimic shiner *(Notropis volucellus)*	Maximum of 2 in 1 season; too small to be retained well by the traps.
Bowfin *(Amia calva)*	Rare in Lake Superior; 1 specimen from the Middle River, June 1, 1960.
American eel *(Anguilla rostrata)*	One specimen from Beaver Lake Outlet, 1957.

Susceptibility of species to electric fields

The alternating-current electric fields were capable of inflicting heavy mortality upon all species of fish. Size and habits influenced the extent of mortality of a given species of fish at a barrier. It also became apparent that certain species were less susceptible than others to the electric current. Outstandingly resistant were bullheads. Yellow perch, rock bass, and pumpkinseeds also had a very light kill.

The large size of the spawning white suckers, longnose suckers, and rainbow trout made them more susceptible to injury or death from the electric fields. The suckers occurred in such large numbers that even a small percentage mortality of the total could give several hundred dead individuals. Rainbow trout, like the suckers, also were killed easily by the alternating current. Even though mature rainbow trout appeared at the barriers in comparatively small numbers, they are so highly esteemed by sport fishermen that their mortality created a public-relations problem.

Few of the other species offered difficulties except in isolated situations or at particular devices. Smelt, which appeared in extremely large numbers some seasons, caused little trouble. The high water of the period of the smelt run produces water velocities favorable for the survival of smelt.

Some data were obtained on the mortality of fish returning downstream through the barriers after spawning. At a number of the control devices all rainbow trout, longnose suckers, and

white suckers were marked by clipping a portion of a fin before they were released upstream. This mark permitted easy identification of fish killed while moving back downstream. Mortality of fish on their return toward the lake varied from stream to stream but generally was low. In only 1 river did the kill reach 10 percent of the total number released above the barrier.

The number of marked fish killed during downstream movement did make a significant contribution to the total mortality at some of the barriers — as much as 33.0 to 62.5 percent. High water velocity lessened mortality of fish moving down through the barriers.

Measures to decrease mortality of fish

Considerable effort was put forth continually to reduce mortality. The installation of direct-current diversion devices on "problem" streams, improvements of traps, installation of abutments, and other modifications to barriers contributed to a steady reduction in the number of fish killed. Mortality of white suckers in 1955 was 55.7 percent of the total number handled. The percentage of kill was gradually reduced to 17.1 percent by 1960 (Fig. 2). Mortality among longnose suckers dropped from 32.5 percent in 1955 to 13.6 percent in 1960, and for mature rainbow trout the kill dropped from 51.8 to 18.8 percent. The actual mortality was smaller as many live fish remained below the barriers and hence were not "handled."

The operation of the electric barrier on the Brule River in 1960 offers an outstanding example of low mortality with a device having a lethal potential. Some 98,800 fish, including sea lampreys, were trapped but only 392 were killed (Table 9).

Frequently the traps became full of suckers so that large numbers were held in the stream below the barriers. The possible effect of this delay has not been determined. Usually, suitable spawning habitat existed downstream from the barrier. Blockage at the barriers at times did cause heavy spawning in a limited length of stream. No indication of any change in species composition or relative abundance of different species has been detected, however, as a result of the barriers. Annual fluctuations in numbers of rainbow trout, longnose suckers, and white suckers have been without trend over a 7-year period (Table 10).

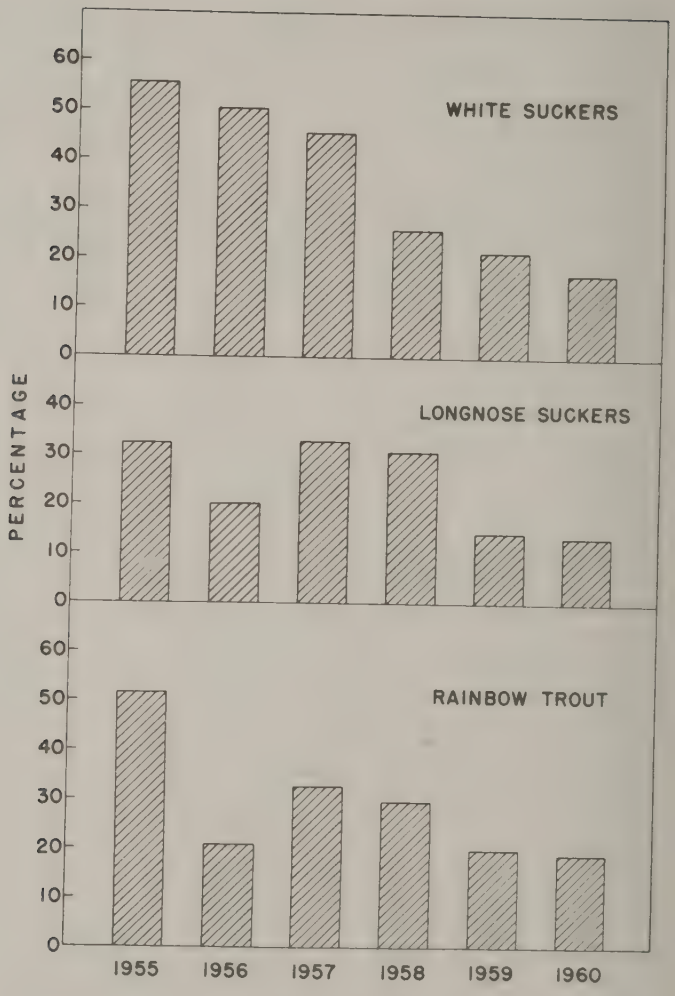

Figure 2.--Percentage mortality of white suckers, longnose suckers, and rainbow trout expressed in terms of numbers handled at the electric barriers, 1955-60.

Table 9.—Total number of sea lampreys and fish trapped and electrocuted in the Brule River, 1960

	Number trapped	Number electrocuted
Sea lamprey	9,712	43
Silver lamprey	149	0
Rainbow trout (large)[1]	75	17
Rainbow trout (small)	278	1
Brown trout (large)[1]	232	45
Brown trout (small)	322	2
Brook trout	2	0
American smelt	72,000[2]	150
White sucker (large)[3]	1,054	10
White sucker (small)	1,057	3
Longnose sucker	11,073	113
Northern redhorse	10	3
Golden shiner	177	0
Creek chub	315	2
Common shiner	239	0
Spottail shiner	6	0
Lake chub	1,076	0
Hornyhead chub	1	0
Longnose dace	11	0
Black bullhead	84	0
Stonecat	273	1
Northern pike	19	0
Burbot	7	0
Trout-perch	270	1
Yellow perch	307	0
Walleye	13	0
Logperch	3	0
Johnny darter	2	0
Smallmouth bass	1	1
Pumpkinseed	1	0
Rock bass	6	0
Mottled sculpin	34	0
Unidentified	5	0
Total	98,814	392

[1] Over 12 inches, total length.

[2] Estimated catch.

[3] Over 9 inches, total length.

Table 10.—Total number of rainbow trout,[1] white suckers, and longnose suckers handled at control barriers in 9 Lake Superior streams over a 7-year period, 1954-60

Stream	1954	1955	1956	1957	1958	1959	1960
Two Hearted River							
Rainbow trout	80	77	152	274	205	380	208
White suckers	1,375	831	3,705	2,245	2,336	2,341	718
Longnose suckers	1,860	527	2,128	2,076	2,641	2,366	934
Sucker River							
Rainbow trout	22	59	36	31	64	64	175
White suckers	468	1,247	1,258	291	1,474	2,302	2,776
Longnose suckers	36	86	179	217	276	222	548
Hurricane River							
Rainbow trout	24	235	387	311	131	199	269
White suckers	0	3	0	0	0	0	0
Longnose suckers	17	174	11	24	0	0	0
Miners River							
Rainbow trout	10	56	144	94	40	105	83
White suckers	176	156	135	343	79	942	592
Longnose suckers	265	795	419	581	7	486	517
Laughing Whitefish River							
Rainbow trout	12	39	71	68	43	23	19
White suckers	265	152	489	146	591	452	262
Longnose suckers	1,333	446	4,695	3,517	3,456	834	1,710
Chocolay River[2]							
Rainbow trout	46	86	126	62	40	24	13
White suckers	3,126	694	2,050	1,934	3,076	3,165	1,845
Longnose suckers	26,023	4,034	5,389	4,943	3,812	5,611	2,712
Huron River							
Rainbow trout	20	36	146	219	413	623	245
White suckers	285	546	697	1,185	3,272	3,915	1,803
Longnose suckers	3,098	2,275	5,669	8,269	10,164	9,276	5,992
Silver River							
Rainbow trout	10	30	55	64	87	40	21
White suckers	6,420	3,349	4,981	3,172	5,770	4,778	3,748
Longnose suckers	143	136	77	135	150	43	71
Firesteel River							
Rainbow trout	5	17	21	28	25	43	45
White suckers	642	1,273	1,439	2,028	3,737	4,776	3,567
Longnose suckers	1,525	1,944	3,624	3,873	2,826	6,733	3,432

[1] Over 12 inches, total length.

[2] A mechanical device was operated on the Chocolay River in 1954. The trap was emptied more frequently than is done at any of the electric devices. It is believed that the frequent cleaning of the trap accounted for the large number of fish handled that year.

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Electrode array for the D.C. diversion device in the Two Hearted River, Luce County, Michigan. The array joins the lead to a trap located at the abutment on the far side of the river. The suspended electrodes of the A.C. barrier can be seen to the left (upstream) of the D.C. array.

Effectiveness of the Experimental Barriers

The potential effectiveness of the experimental electric barriers for the control of the sea lamprey cannot be evaluated accurately. Some streams used by the sea lampreys for spawning on both the Canadian and U.S. sides of Lake Superior lacked barriers. Most of the barriers were not operated through enough seasons to be expected to reduce the numbers of adults. Improvement of the efficiency of some of the control devices was slow because of limited experience during the early years of operation.

The exact number of years barriers must be operated and the necessary level of efficiency required to effect a suppression in numbers of sea lampreys are unknown. Investigators have estimated the duration of larval life from 41 months to 7 years or more (Gage, 1928; Applegate, 1950; Wigley, 1959; and Stauffer, 1962). Data from growth studies of populations reestablished after chemical treatments and observations of an isolated known-age group have provided a reliable means of separating the first 2 age groups. In some rivers, the third age group is distinguishable but larger ammocetes cannot be grouped by age. Early data from the known-age ammocetes definitely indicate the larval stage will exceed 4 years from the date of hatching.

It is clear, nevertheless, that under the proper conditions electric barriers of the type and design used are capable of blocking entire runs of adult sea lampreys. The data from 2 streams can serve as examples of evidence on this point. The Brule River had the largest known sea lamprey run on the U.S. side of Lake Superior. Its barrier was first operated during the 1958 migratory season. The river was chemically treated in April, 1959. Members of the 1958 year class were lacking in the larval collections. The Fish Creek device was first operated in 1957. This stream also was treated in the spring of 1959. Both the 1957 and 1958 year classes were missing. Similar observations on other streams gave further evidence of effectiveness. In still others the presence of ammocetes of all sizes after years of barrier operation proved the need for additional improvements of function.

Continued experience with the barriers assuredly would have carried the efficiency to a much higher level than was achieved through 1960, but the rare mechanical breakdown, the occasional excessive flood, and upstream movement of a few spawners before barriers could be activated still would have kept the method short of perfection.

Summary and Conclusions

The threat of total destruction to the last remaining natural stocks of lake trout in the upper Great Lakes demanded an effort to control the sea lamprey in Lake Superior with the least possible delay. The electric barriers as developed in streams tributary to Lakes Huron and Michigan offered the only known, economically feasible tool available when the program started. The method's most serious weakness lay in the number of years the barriers needed to be operated before benefit could be expected. Each generation already present in the streams as ammocetes had to reach the age of transformation and go through the parasitic stage before it became susceptible to control.

The failure of sea lampreys to use all streams that apparently offer suitable spawning conditions[7] made the control attempt practical. An undesirable situation was created by the fact that shortages of funds stretched the period of installation over several years and forced delay in the installation of a barrier in a particular stream until the use of that stream by lampreys was definitely established.

A further difficulty lay in the unavoidable slowness in recognizing the inefficiencies of the original devices, and the time required to gain the knowledge and experience to redesign, modify, and improve the barriers to make them function properly in a wide variety of conditions.

The need to protect fish at the barriers contributed to some inefficiency. Nearly all fish species were more susceptible to injury or death than were sea lampreys. Far too often, the intensities of the electric fields were maintained at an undesirably low level to reduce the mortality of fish.

The great length of the Lake Superior south shore, the poor condition of many roads, problems of access, and a shortage of trained personnel also contributed to the time required to overcome some deficiencies of barriers and barrier operation.

The catch of sea lampreys increased rapidly from 1953 to 1958. The numbers of adults dropped substantially in 1959 and again in 1960. Although the barriers may have contributed to the 1959-60 decreases, they can not be given major credit for the reduction in numbers of sea lampreys. Not all streams were blocked and many of the barriers had not been operated

[7] As late as the end of 1962, sea lampreys were known to inhabit only 71 streams tributary to the U.S. waters of Lake Superior.

for a sufficient number of years to end production of parasites by the streams. Many which had been in operation for several seasons were ineffective during the earlier years. It is doubtful, therefore, that a sufficient level of efficiency had been reached in time to have contributed greatly to the decrease in numbers in 1959 and 1960.

The experimental attempt to suppress numbers of sea lampreys in Lake Superior with electricity was terminated at the end of the 1960 season. An exact answer to its possible ultimate effectiveness will remain unknown. The operation did make significant contributions to knowledge and provide some important conclusions. The most obvious are:

1. It is possible to block the upstream migration of sea lampreys or fish with electric barriers of the design and type developed and used.

2. The electric barriers are subject to mechanical failures or breakdowns. Although the frequency of interruptions of operation can be reduced greatly, some escapement is to be anticipated each season at 1 or more barriers in a system.

3. Because the method of control requires continuous operation over a number of years, the opportunity for inefficiency as the result of abnormal conditions is increased accordingly.

4. Some reproduction, although possible minor, could occur from the few migrants that move upstream before it is possible to activate the barriers in the spring.

5. The electric barriers provided considerable information on sea lamprey runs and populations of lampreys and other fishes in the waters of Lake Superior. Valuable data also were collected on temperature, stream discharge, and other biological, ecological, and physical characteristics of streams tributary to Lake Superior. Information accumulated during the operation was most useful in the application of the selective larvicide.

6. The electric barriers prevented the establishment of ammocete populations in some streams and limited the size of ammocete populations in others. The chance for success in the initial chemical treatments was increased correspondingly.

7. Development and use of electricity for sea lamprey control contributed to knowledge of methods and techniques in the use of electro-fishing gear in fishery management and research.

8. The electric barriers assumed a new importance when their use for experimental control was terminated. The devices became the principal means for the evaluation of the results of the chemical control.

Acknowledgments

The long term and the wide scope of this investigation have involved far too many people for us to acknowledge each contributing individual. Nearly all of the Bureau staff in the Great Lakes during the years 1953 through 1960 contributed directly or indirectly to the sea lamprey control program. The cooperation and assistance extended by the Conservation Departments of the States of Michigan and Wisconsin are appreciated.

The study was conducted under the direction of James W. Moffett, Director, and Leo F. Erkkila, Assistant Director, Bureau of Commercial Fisheries Biological Laboratory, Ann Arbor, Michigan. Ralph Hile advised in the preparation of the manuscript.

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Tuna Behavior

A growing field for research

By

Thomas A. Manar

Some years ago, a group of scientists rom the University of Hawaii led by Professor Albert L. Tester and backed by a contract with the US Bureau of Commercial Fisheries, showed that Little Tunny (the fish that in Californ-a is called "black skipjack") are able o perceive tastes or odors found in nvisible extracts of shrimp, squid, or una flesh.

Until recently, these findings rep-resented just about the only conclusive aboratory studies of the sensory abil-ties of tunas. Yet what and how an nimal sees and smells and hears stands as the cornerstone of its behavior.

This gap in scientific knowledge has resulted not from lack of interest on he part of scientists, but from the fact hat although it is a savage fighter at he end of a line, the tuna is a delicate creature and difficult to maintain in captivity. Occasional successes such as hose of the University of Hawaii in keeping Little Tunny have been out-veighed by frequent failures.

It is only within the past three years hat methods of handling have been sufficiently improved to provide tunas for shoreside research on a regular basis. Now, not far from the carefree beaches of Waikiki, the Bureau's Bio-ogical Laboratory, Honolulu, has es-ablished a research facility that is the only one in the world at which re-searchers are assured a year-round supply of living tunas for investigation of the sensory abilities and behavior of the fish.

The Kewalo facility has allowed Honolulu Laboratory scientists to es-tablish some "firsts." Among them are:

—the first measurements of the visual acuity of tunas;

—the first measurements of the hearing ability of tunas;

—the first measurements dealing with the hydrodynamics involved in the tuna's maintaining swimming depth.

And from studies conducted by a Honolulu Laboratory scientist at Marineland of the Pacific, Palos Verdes, California, has come another "first":

—the first reported observations of courting and pairing in the scombrids, the family of fishes to which the tunas belong.

The practical aim of studies such as these is to provide the solid scientific background upon which improved gear and fishing techniques can be based and new methods of locating tunas in the sea developed. Scientifically, the studies are interesting in themselves and provide new clues to such biological problems as schooling behavior and migrations, matters which also influence the fishery.

Mr. Manar, author of the article beginning on this page, is chief of the Publication Services Branch of the US Bureau of Commercial Fisheries Biological Laboratory in Honolulu, Hawaii.

Underwater "Eye"

For many years, most investigations of tuna behavior were limited to observations made from vessels at sea and to the indirect evidence afforded by such statistics as those from the longline catch. Not until 1960 was a fishery research vessel equipped with viewing ports below the waterline, providing the scientists with a "tuna's eye view" of the sea. The ship was the Honolulu Laboratory's *Charles H. Gilbert*.

The *Gilbert's* viewing chambers allowed several new observations on the behavior of tuna schools. For example, scientists found that there was no such thing as truly "mixed" schools of adult Yellowfin and Skipjack tunas. Adjacent schools might feed in the same place, and hence appear in the same catch, but schooling between separate species was brief, almost momentary.

Motion pictures taken from the *Gilbert* have provided data that Honolulu Laboratory scientists have ingeniously handled to estimate the swimming speeds of Yellowfin and Skipjack tunas in schools that were feeding. The

Expert fishermen aboard the research vessel **Charles H. Gilbert** catch tunas for study at the US Bureau of Commercial Fisheries Biological Laboratory, Honolulu.

Fisherman and technicians maneuver a tuna over the opening of a specially designed tank. When tension on the line is relaxed, the fish shakes off the hook.

swimming speeds of the Yellowfin tuna turned out to be from 3.2 to 10.9 miles per hour. These results fall between those reported for Yellowfin swimming at a depth of about 350 feet (2 miles per hour) and struggling at the end of a fishing line (40.8 miles per hour). The swimming speeds of the Skipjack tuna (0.6 to 13.9 miles per hour) are lower than those found by other researchers (about 20.2 miles per hour). The reason for this difference is unknown.

The viewing ports thus provided interesting new information on the tuna, but many aspects of the creature's sensory abilities and behavior cannot be studied in the vast and ever-changing sea. Measurement of sensory abilities, certainly, required that the animal be placed in a controllable environment, which the sea never is. Hence the value of the Kewalo facility to research.

Tunas can now be kept at Kewalo for several months. The secret lies in extremely careful handling. The newly caught fish are transported to Kewalo in portable tanks aboard the *Gilbert*. These specially designed fiberglass tanks are lifted from the deck by a crane and carried to the experimental tanks nearby. The portable tank is lowered into the water. Fishery biologists tip it to let its living cargo swim free. The fish are never touched.

Such methods, plus the fact that it is possible to catch tunas the year around close to Honolulu, have assured the behavior scientists a constant supply of experimental animals.

So little is known of the tuna's behavior that it was necessary for the Honolulu scientists to begin their shoreside work with the basic facets of sensory ability. They used methods developed in studies of such mammals as dogs, cats, and rats. In these, the animal is taught that a certain stimulus means a reward (food), another, punishment (an electric shock). When the animal is trained, it will react to the stimulus in the absence of the food or electric shock.

Tuna's Eyesight Measured

In experiments aimed at measuring visual acuity, the fish is required to respond to a pattern of black bars on an illuminated opal-glass square. These experiments have shown that the Yellowfin see bright objects better than the Skipjack tuna, the Skipjack better than the Little Tunny; at lower brightness, there are only negligible differencees among the species. Some of these apparent capacities may be connected with the size of the fish tested. This possibility is being studied now. Broadly speaking, visual acuity is a measure of the ability to distinguish details. The results mean that a distant object will blur sooner for the Little Tunny than the Skipjack tuna, and sooner for the Skipjack tuna than the Yellowfin tuna. None of the fish, by the way, sees as well as does a man, since man has eyes more highly developed for acute vision.

Other aspects of vision such as depth perception and color perception and—what may be critically important — the ability to perceive slight movements, have not as yet been tested

Eyesight is one of the dominant senses of the tunas as it is with birds and man. It plays a major role in the tuna's schooling behavior and in the attack on prey. Whether the ability to hear may play a part in the tuna's behavior is uncertain. So far as is known, the tunas produce no sounds, but the evidence is so scanty that the possibility of sound production cannot be ruled out. On the other hand, as has been proved conclusively by Honolulu Laboratory scientists, this apparently silent fish hears well. There is a range of frequencies above which it cannot hear, but that is true for man, too, whose ears are far less acute than those of a dog, for example, or a bat. In the Yellowfin tuna, the only one that has been tested, the upper cutoff lies at about 2,000 cycles per second, far below man's maximum of about

),000 cycles per second. The Yellow- ı tuna hears best sounds that are the neighborhood of 500 cycles per cond, or slightly above middle A on e piano. It hears sounds of lower equencies better than man does; the ıtoff point is at less than 40 cycles :r second.

The chemical senses of fishes are :markably acute. Some salmon, for xample, can detect an odor in a di- ıtion of one part in 80 million. The (onolulu Laboratory plans to follow p on Prof. Tester's original work on hemoreception with a view to de- :ribing the chemoreceptory abilities f the tunas and determining what art they play in the behavior of the :sh.

Tunas are capable of bursts of reat speed, reaching rates that make hem among the fastest fish alive, but heir normal swimming speed in the anks is rather slow, about 2 miles per ıour, a pace that in a man might be :alled "sauntering." To the tuna, wimming means much more than lo- :omotion. Requiring oxygen, the crea- ure must swim to ventilate its gills; ɔeing heavier than water, it must swim o keep from sinking. One study under way at Honolulu is aimed at a clearer ınderstanding of the hydrodynamics ɔf swimming in the tunas.

A striking piece of information dealing with tuna behavior has come from work conducted by a Honolulu Laboratory scientist not in his home laboratory but in Marineland of the Pacific. There, he and Marineland's Curator of Fishes observed the first recorded courtship and pairing among the scombrids. The fish was the Pacific Bonito. It has been generally assumed among scientists that fairly large, schooling, pelagic fishes such as these do not pair. It was thought that the females spawned and the males fertilized the eggs at random. With the Pacific Bonito, however, courtship and pairing have now been observed. After a brief courtship, the male and female leave the school. The female swims in a tight circle as she extrudes eggs. The male follows her exuding milt. The process is brief, lasting only 1 or 2 minutes.

Much of the emphasis in behavioral research at Honolulu during the past few years has been put on tunas in tanks. The recent behavioral research conducted at sea has been from a small craft, a 12-foot-square raft called the *Nenue*. Equipped with an underwater viewing chamber, the *Nenue* has allowed scientists to observe the behavior of fishes under and around a drifting object, which was the raft itself. It has long been known that fish accumulate near flotsam; some small commercial fisheries have been based on this fact. The scientists aboard the *Nenue* found that when the raft was first placed in the ocean no fish were to be seen. And after a drift of several days, hundreds of fishes, most of them small, were clustered around and under the raft. Why this should be—what attraction the raft has for the fish—has not been finally settled. It seems clear, however, that the obvious answers—a shelter from predation and, conversely, a convenient place to find food—may be important.

Tunas and Teenagers

The tunas are allelomimetic creatures, that is, like teenagers, each does what its fellows are doing. Tuna schools are examples of such behavior. Men are most familiar with tuna schools that are actively feeding. Whether schools remain intact for months or years, whether the fish disperse at night, how deep the schools swim—all these and a host of other questions are unanswered. And answers are important to the fisheries. For example, scientists are convinced that there are enormous untapped tuna resources in the central Pacific, but their harvest must wait until it is learned how to locate them, and basic to that process is knowledge of their behavior.

The best existent device for studying the behavior of schools of tunas appears to be one of the sophisticated new sonars. A continuous-transmission, frequency-modulated model is being constructed and will be installed aboard the *Townsend Cromwell* late in the fall of 1965. With it, Honolulu Laboratory scientists believe that they will be able to describe the depth distribution and geographic distribution of tuna schools, feeding or not, something impossible to do at present.

On the horizon is an even more potent device. A few months ago, Secretary of the Interior Stewart L. Udall announced that a study sponsored by the Bureau of Commercial Fisheries shows that it is feasible to build up a specially designed nuclear-powered submarine for fishery and oceanography research. Most of the preliminary studies for this submarine have been made at the Honolulu Laboratory. The submarine would be able to operate anywhere in the upper 1,000 feet of the ocean, achieve speeds of 20 knots (fast enough to keep up with tuna schools), and ignore bad weather, which often hinders present research craft. The research submarine is planned for the 1970s. Capable of scores of uses in fisheries and oceanography, the research submarine should cast new light on the problems of tuna behavior.

The next decade should also see improvement of the behavior facilities at Kewalo Basin. Although they have provided fresh and basic information, their capacities are limited, and they are primitive compared to facilities available to researchers studying fishes more easily kept in captivity.

The behavior group at the Honolulu Laboratory consists of five scientists. Few as they are, these men are pioneering a field that will probably become increasingly important in fisheries research during the coming years.

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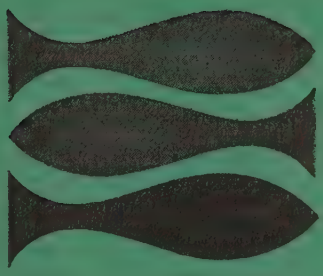

INTERNATIONAL NORTH PACIFIC FISHERIES COMMISSION

BULLETIN NUMBER 15

SALMON OF THE NORTH PACIFIC OCEAN

PART V

OFFSHORE DISTRIBUTION OF SALMON

by J. I. Manzer, T. Ishida,
A. E. Peterson and M. G. Hanavan

VANCOUVER, CANADA, 1965

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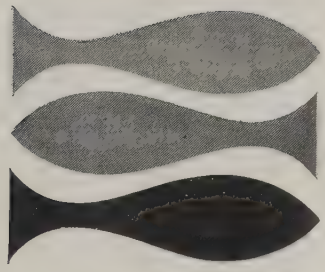

INTERNATIONAL NORTH PACIFIC FISHERIES COMMISSION

Established by Convention between Canada, Japan and the United States for the Conservation of the Fisheries Resources of the North Pacific Ocean

BULLETIN NUMBER 15

SALMON OF THE NORTH PACIFIC OCEAN
PART V
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by J. I. Manzer, T. Ishida,
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PREFACE

This bulletin contains Part V of the comprehensive report entitled *Salmon of the North Pacific Ocean*, which is being prepared and published by the International North Pacific Fisheries Commission. The comprehensive report was described in detail in its introduction, which appeared in Part I (INPFC Bulletin No. 12, 1963). The various parts of the comprehensive report are being published separately as they become available and not necessarily in numerical order. Those parts which have been published thus far are listed overleaf.

Part V consists of a description of the offshore distribution of salmon as determined from information obtained from research vessel operations and records of commercial fishing vessels. It has been written jointly by authors representing the three national sections of the Commission.

Research reports submitted to the Commission for publication in the bulletin series must first receive approval for publication from three scientific referees. These referees are Dr. Tasuku Hanaoka, Chief of the Research Division of the Fisheries Agency of Japan; Mr. Donald L. McKernan, Director of the United States Bureau of Commercial Fisheries and Dr. Peter A. Larkin, Director of the Fisheries Research Board of Canada's Biological Station at Nanaimo, B.C. Following approval of the scientific referees, papers must receive the approval of the Commission.

Bulletins of the Commission are published separately in English and Japanese. The original language is indicated and accuracy of translation is the responsibility of the Secretariat.

WILVAN G. VAN CAMPEN
Executive Director
July, 1964

SALMON OF THE NORTH PACIFIC OCEAN

Part I. Introduction and Catch Statistics for North Pacific Salmon
Part II. Review of Oceanography of the Subarctic Pacific Region
Part V. Offshore Distribution of Salmon

SALMON OF THE NORTH PACIFIC OCEAN—PART V
OFFSHORE DISTRIBUTION OF SALMON

by

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September 1963

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Received for publication October 23, 1963. Original, English.
Source: Joint reporting team, Committee on Biology and Research. INPFC Document No. 622.
Bull. 15, Int. North Pacific Fish. Comm., 1965.

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I. INTRODUCTION

The Protocol to the International Convention for the High Seas Fisheries of the North Pacific Ocean, to which Canada, Japan and the United States are Contracting Parties, states that the three countries shall determine as expeditiously as practicable whether Pacific salmon (genus *Oncorhynchus*) originating in the streams of North America intermingle on the high seas with salmon originating in the streams of Asia and, if so, whether a line other than the existing provisional line permitting Japanese high seas salmon fishing as far east as Longitude 175°W can be shown to divide the salmon originating in the two continents more equitably.

Starting in 1955, a cooperative research program, which included several lines of investigation, was instituted by the three countries to solve these problems. The program was designed to determine the distribution of salmon of various origins on the high seas and the relationships between distribution and migration of salmon and the ocean environment.

Essential to the solution of the Protocol problem is a comprehensive description of the distribution of salmon on the high seas. In 1959, the International North Pacific Fisheries Commission (INPFC) established a working party to prepare such a report without reference to continental origin of salmon. It was indicated that all pertinent information resulting from the Commission's joint research program and from catch statistics and biological data derived from sampling the Japanese high seas commercial salmon fishing operations should be included. The purpose of this report is to make available the agreed results of joint analyses of the large volumes of catch statistics and biological data and to list in detail the data upon which the analyses are based, thus providing a convenient reference source for scientists engaged in specialized studies related to the Protocol, as well as other fishery scientists.

The nomenclature used in this report regarding salmon follows. Common synonyms appear in parentheses.

Sockeye (red) salmon—*O. nerka*
Chum (dog) salmon—*O. keta*
Pink (humpback) salmon—*O. gorbuscha*
Coho (silver) salmon—*O. kisutch*
Chinook (king, spring) salmon—*O. tschawytscha*

II. SUMMARY OF SCIENTIFIC KNOWLEDGE PRIOR TO 1955

Research on salmon on the high seas was conducted

at various levels of intensity for several decades and can be conveniently separated into pre- and post-World War II periods. During the pre-World War II period, small-scale fishing investigations were initiated by Japan in the 1920's off the east coast of Hokkaido. These were shortly expanded northward to the northern Kuril Islands and subsequently led to the driftnet fishery in that area. As a result of this development, studies, primarily tagging, were conducted during the period from 1935 to about 1942 to determine the effects of the fishery on the stocks off the northern Kurils and to learn more about salmon migrations (Hirano, 1953a, 1953b). During the early years of this period, investigations were also conducted by Japan in the Japan Sea (Korean Government-General, Fisheries Experiment Station, 1930 and 1936; Yoshida, 1942) and in the Okhotsk Sea by the U.S.S.R. (Pravdin, 1940). As Japanese commercial interests in salmon extended into the northwest Pacific Ocean, studies became more closely associated with this fishery. Also, from 1939 to 1941, experimental fishing was carried out by the United States in the eastern Bering Sea and Aleutian Islands (Barnaby, 1952).

It was not until after World War II, however, that information on salmon in vast areas of the northwest Pacific Ocean began to amass. Catches made by the rapidly-growing mothership and landbased operations were sampled and catch statistics were collected. (Development of the mothership fishery and sampling of the catches are described in Section III, B.) In conjunction with these expanding operations, certain areas were further investigated through the employment of research vessels (Kubo and Yamahira, 1953 and 1955; Yamahira, Matsushita and Otsuru, 1955).

Many reports have been prepared, some unpublished, which describe the findings and results of investigations since interest was first shown in Pacific salmon in their ocean environment. A brief summary of available knowledge on this aspect of the salmon's life acquired up to 1955, when the Commission instituted its research program, follows. This summary, based on a reasonably thorough canvass of the literature, includes only the major findings reported to that time. It is possible that other findings, equally important, were inadvertently omitted because of inaccessibility of the reports.

A. General Marine Distribution

Commercial and experimental driftnetting by the Japanese and experimental fishing by the Russians and Americans during the summer months in different years have shown salmon to occur over wide areas of the western North Pacific and adjacent waters. As early as the early 1930's, salmon were known to be present in large numbers off the east coast of Paramushir Island (northern Kurils), off the southern part of west Kamchatka and off east Kamchatka in the vicinity of Kamchatka Bay offshore to the Komandorski Islands (Yokoyama and Hanai, 1931). Waters in the vicinity of the northern Kuril Islands were excellent salmon driftnet grounds, yielding sockeye, chum and pink salmon, largely. The timing of these species through the area was given as follows (Yokoyama and Kawakami, 1932): Sockeye: *Start*, June 1; *Peak*, June 15-July 15; *End*, End of July. Chum: *Start*, June 19; *Peak*, July 9-July 30; *End*, August 15. Pink: *Start*, June 24; *Peak*, July 10-August 5; *End*, August 20.

Waters off the Pacific coast of Hokkaido and northern Honshu also have been the subject of study over a prolonged period of time. Arii (1934) reported on the results of interviews with fishermen operating in coastal waters (20–30 nautical miles offshore) as well as on experimental studies. Pink and chum salmon were present in sufficient numbers to support a driftnet fishery. The southern limit of these species would appear to be about Kinkazan Island (off northern Honshu), reaching this latitude during February-March. Their northward migration through waters off the Pacific coast of these islands did not begin until surface water temperatures began to rise in April and May.

Early post-World War II studies by the Hokkaido Prefectural Fisheries Research Station within coastal waters confirmed previous findings, according to unpublished reports. West of Cape Erimo, Hokkaido, chum salmon migrations reached a peak during late May, when water temperatures reached about 8°C. The proportion of pink salmon in the catches increased after this time. In waters east of Cape Erimo, chum salmon appeared in early May and reached a peak, according to the fishery, between late May and early June. The peak fishing period for pink salmon was slightly later, mid-June to late June, thus reflecting the same general pattern as observed west of Cape Erimo. Smaller catches were made as late as early July. Somewhat further offshore, according to investigations from late April through early May 1951, chum salmon were caught between Kinkazan Island and Tsugaru Strait (Hokkaido University, Faculty of Fisheries, 1953). Pink salmon were not caught, but their absence in these waters cannot be concluded since large-meshed gillnets (4.2 sun, or approximately 5.0 inches) were used.

Further north, in waters east of Hokkaido and off the southern Kurils in 1952 and later, more informa-

tion was obtained on the distribution and occurrence of pink and chum salmon (Kushiro Branch, Hokkaido Prefectural Fisheries Research Station, 1954; Fisheries Agency of Japan, 1955). West of Longitude 150°E and south of Latitude 43°N, chum salmon were abundant from April to early or mid-June, while pink salmon occurred in this area from early June to early July. In waters west of Longitude 150°E and north of Latitude 43°N, chum salmon were caught from late June to early July and pink salmon from late June to mid-July. Off Urup Island (immediately north of Hokkaido), both pink and chum salmon were less abundant. Between Latitudes 45°N and 47°N east of Longitude 150°E, pink salmon were abundant in July.

The best information regarding salmon in the northwest Pacific prior to 1955 has been derived from studies related to the development of the post-World War II Japanese mothership fishery which began on a limited scale in 1952. Several reports, published and unpublished, by both Japanese and United States investigators, have been prepared on various aspects of the distribution and biology (age, size, maturity, etc.) of the various salmon species, as indicated by sampling catches made by these operations (Kubo and Yamahira, 1953 and 1955; Fukuhara, 1953; Yamahira, Matsushita and Otsuru, 1955). Perhaps the most detailed report available generally is that by Fukuhara. Using daily commercial catch records of the largest of three mothership fleets operating in 1952, he was able to show changes in the species composition of the catch as well as in the distribution and abundance of salmon in waters south of the western Aleutians in May and June and southeast of Kamchatka in July. The occurrence of all species but chinook in waters immediately south of the central Aleutians as far east as Longitude 169°W between early June and mid-July was established by Schaefers and Fukuhara (1954).

During investigations in the eastern Bering Sea and Bristol Bay during June and July of 1939–1941, inclusive, salmon were caught generally and as far west as Semisopochnoi Island (Longitude 180°) along the Aleutian Chain (Barnaby, 1952). Sockeye and chum salmon were the major species in each year.

In the Okhotsk Sea, scattered observations made off the west coast of Kamchatka as far as 100 miles offshore shed some light on the offshore distribution of salmon in that area. According to Alperovich as quoted by Pravdin (1940), at least pink salmon were present this far offshore. Sockeye were also reported caught but no offshore limits were described.

In the Japan Sea off Japan, pink salmon were caught during late February in Toyama Bay (Latitude 38°N), but were not abundant until late March. As the season advanced, concentrations were found successively northward. During May and June, they were encountered by the fishery operating southwest of Hokkaido. Off northeastern Korea, pink salmon measuring 20–30 cm in total length were taken in traps from late November through December and again between early April to early June (Yoshida, 1942). These findings suggest that pink salmon in the Japan Sea migrate southward during the fall and northward during the spring, and that the southern limit in winter is located between North Korea and the Noto Peninsula, Japan (Latitude 37°N), coinciding with the Polar Front.

B. Vertical Distribution

As far as can be ascertained from the literature very little experimental fishing specifically designed to study the vertical distribution of salmon had been conducted in any area of the North Pacific and adjacent waters prior to 1955. What information exists on this aspect of distribution is largely speculative and was based on observations made on the distribution of the catch in floating driftnets fishing varying depths from the surface. Further, the catches were usually the results of fishing during the hours of darkness. In general, salmon were caught in the upper layers close to the surface (Pravdin, 1940; Barnaby, 1952; Fukuhara, 1953). Barnaby reporting on catches resulting from experimental fishing and Fukuhara reporting on commercial operations both indicated that practically all of the catch occurred within about 10 meters of the surface.

C. Distribution of Immature and Maturing Salmon

Information prior to 1955 on the distribution of salmon was primarily based on commercial fisheries and experimental fishing related to those fisheries. As a general rule, these operations mainly employed large-meshed surface gillnets designed to catch large salmon. The catches therefore reflected the distribution of maturing salmon, mainly. On occasion, however, in some areas small salmon were caught incidentally, thus yielding some information on the distribution of this group. According to Fukuhara (1953), immature sockeye occurred south of the western Aleutians. They were also present in the eastern Bering Sea as were immature chum salmon (Barnaby, 1952).

D. Distribution in Relation to Water Temperature

Off the northern Kuril Islands, sockeye salmon were caught in surface waters having temperatures ranging

from about 1° to 9°C; chum salmon, from about 3.5° to 11°C; pink salmon, from about 4.5° to 11°C. Largest catches, however, for these three species occurred between 3.5° and 7°C, 3.5° and 10°C, and 7° and 11°C, respectively, the differences in the "preferred" temperatures being associated with differences in migration times (Yokoyama and Kawakami, 1932). Off the east coast of Hokkaido, pink and chum salmon migrated northward as water temperatures in April and May began to rise (Arii, 1934). In the Japan Sea, pink salmon were most abundant in waters having surface temperatures between 8° and 11°C and were absent when temperatures rose above 13°C.

III. SOURCES OF DATA AND DESCRIPTION OF OPERATIONS

Information on distribution and relative abundance of salmon in the North Pacific and adjacent seas is based on gillnet catch data from three separate sources: (1) research vessel operations of the three countries forming part of the INPFC research program; (2) the Japanese mothership fishery; and (3) Japanese research vessel operations in the landbased region.

A. INPFC Research Vessel Operations, 1955–1960

The broad geographic coverage by the research vessels of Canada, Japan and the United States throughout the North Pacific Ocean and Bering Sea is shown in Appendix Figure A. Beginning in 1955, gillnetting was carried out annually from May through August, with limited fishing in some years in April, September and October. The purpose of these operations was twofold: (1) to determine salmon distribution and relative abundance in these waters and (2) to collect adequate samples for racial studies and for other biological studies connected with the INPFC research program. Because of the need for adequate samples from specific locations, the latter objective limited to some extent geographic and temporal coverage. Accordingly, research vessel data are primarily useful for showing the distribution and changes in the relative abundance of salmon only in a general way.

The fishing procedure and the kinds of data obtained are described for each member country in detail in the annual reports of the INPFC for 1955 through 1960.

The total number of vessels operated by the three countries in any one year ranged from three to ten. The stations fished by these vessels in the different months of each year since 1955 are shown in detail in Appendix Figure A.

As regards the gillnets used, minor changes have occurred in their construction and mesh size composition since the initiation of the high seas research program. In 1955 and 1956, the Japanese vessels fished

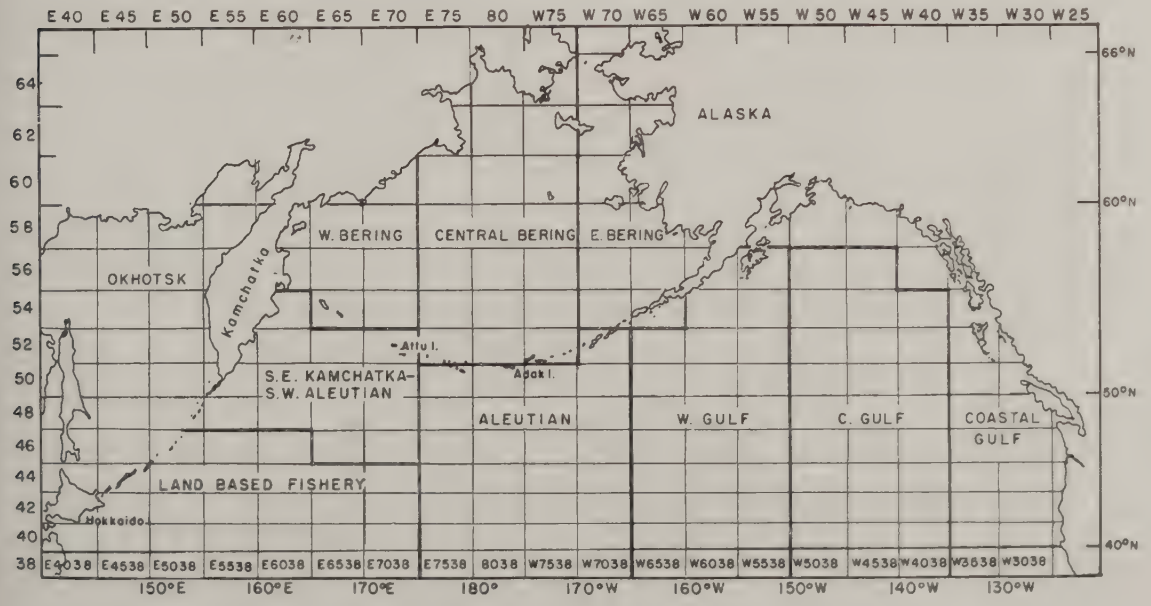

FIGURE 1. High seas regions and statistical areas for research vessels.

with gillnets having 3.0", 3.6", 4.2", 4.8" and 5.4" meshes, diagonal stretched measure. United States vessels in 1955 used gillnets measuring 2.25", 3.25", 4.50" and 5.25". Except for increasing the smallest mesh size from 2.25" to 2.50" in 1956, the mesh sizes used by the United States since then have remained unchanged. Canadian vessels, participating in the high seas studies for the first time in 1956, fished with gear similar to that used by United States vessels. In 1957, in accordance with the agreement reached at the INPFC interim meeting in Tokyo in 1957, the three countries adopted the 2.50", 3.25", 4.50" and 5.25" meshes, stretched measure, constructed from nylon web, as standard, and have used these ever since. Japanese research vessels in 1957 and thereafter, in addition to the INPFC standard gillnets, have continued to use gillnets with 4.8" meshes, similar to those used by commercial vessels.

The standard INPFC gillnets measured 50 fathoms (300 feet or 91.5 meters) in length along the corkline.

The mesh size composition of the gillnets varied within and between years (Appendix Table A). Usually, the ratio of gillnets of 2.50", 3.25", 5.25" mesh to those of 4.50" mesh was 1:3. In 1959 and 1960, this ratio was 1:6 on United States vessels.

The salmon catches and associated data for each vessel are given by set and geographic position in Appendix Table A. To simplify analysis the data have been combined into statistical areas of two degrees of latitude and five degrees of longitude according to 10 regions (Figure 1).

Biological information collected by the three countries through sampling the salmon catches either at sea or later in the laboratory has been reasonably similar and acceptably standardized. Usually, the fork length, body weight, gonad weight and sex were recorded for each fish caught. Also, scale samples were collected for subsequent age determination. Departure from this routine was rare and occurred usually when catches were very large, in which case they were sub-sampled.

B. Japanese Mothership Fishery, 1952–1960

The Japanese mothership fishery, because of its size and intense fishing, is best able to provide detailed information on the distribution, relative abundance and biological characteristics of salmon available to its gear in the fishing areas of the North Pacific, Bering Sea and the Okhotsk Sea.

It must be recognized, however, that commercial fishing data are subject to errors and that the mothership data are no exception in view of the large scale of the operations. It is likely, however, that the general levels and trends in abundance derived from these data are not seriously affected by these errors.

Description of Fishery and Gear

The Japanese high seas mothership salmon fishery consisted of surface gillnetting in the North Pacific and the Bering Sea east to Longitude 175°W and in some years (1955–1958) in the Okhotsk Sea. Several accounts are available which describe the development of this fishery (Fukuhara, 1955; Taguchi, 1957; Research Institute for the Economics of Agriculture and Forestry, 1960). The number of mothership vessels, catcher boats and scout boats engaged annually in this fishery from 1952 to 1960 are given in Table 1.

A typical mothership fleet included a large processing vessel, approximately 30 catcher boats and from two to six scout boats. The catcher boats usually fished within a radius of 30 to 40 miles of their mothership. Except during extremely inclement weather, when catches would be retained, catcher boats discharged their catches each morning. Scout boats, as the name implies, operated further afield in search of salmon concentrations.

Since resumption of the mothership fishery, several changes have occurred in the areas fished (Figure 2). In 1952, when the fishery operated on a limited scale, in addition to exploiting waters off the southeast coast of Kamchatka as in pre-World War II years, the fishery expanded eastward to Longitude 179°E early in the season. During 1953 through 1955, the fishery expanded rapidly. In 1955, for the first time, fishing extended into the Okhotsk Sea. In 1956, the fishery expanded further eastward to about Longitude 175°W

Table 1. Number of mothership fleets, catcher and scout boats in the Japanese high seas salmon fishery, 1952–1960.

Year	Mothership fleets	Catcher boats	Scout boats
1952	3	50	7
1953	3	93	12
1954	7	160	45
1955	14[1]	334	72
1956	16[1]	500	57
1957	16[1]	461[2]	—
1958	16[3]	460[2]	—
1959	16	460[2]	—
1960	12	410[2]	—

[1] Two mothership fleets operated in the Okhotsk Sea.
[2] Includes scout boats.
[3] One mothership fleet operated in the Okhotsk Sea.

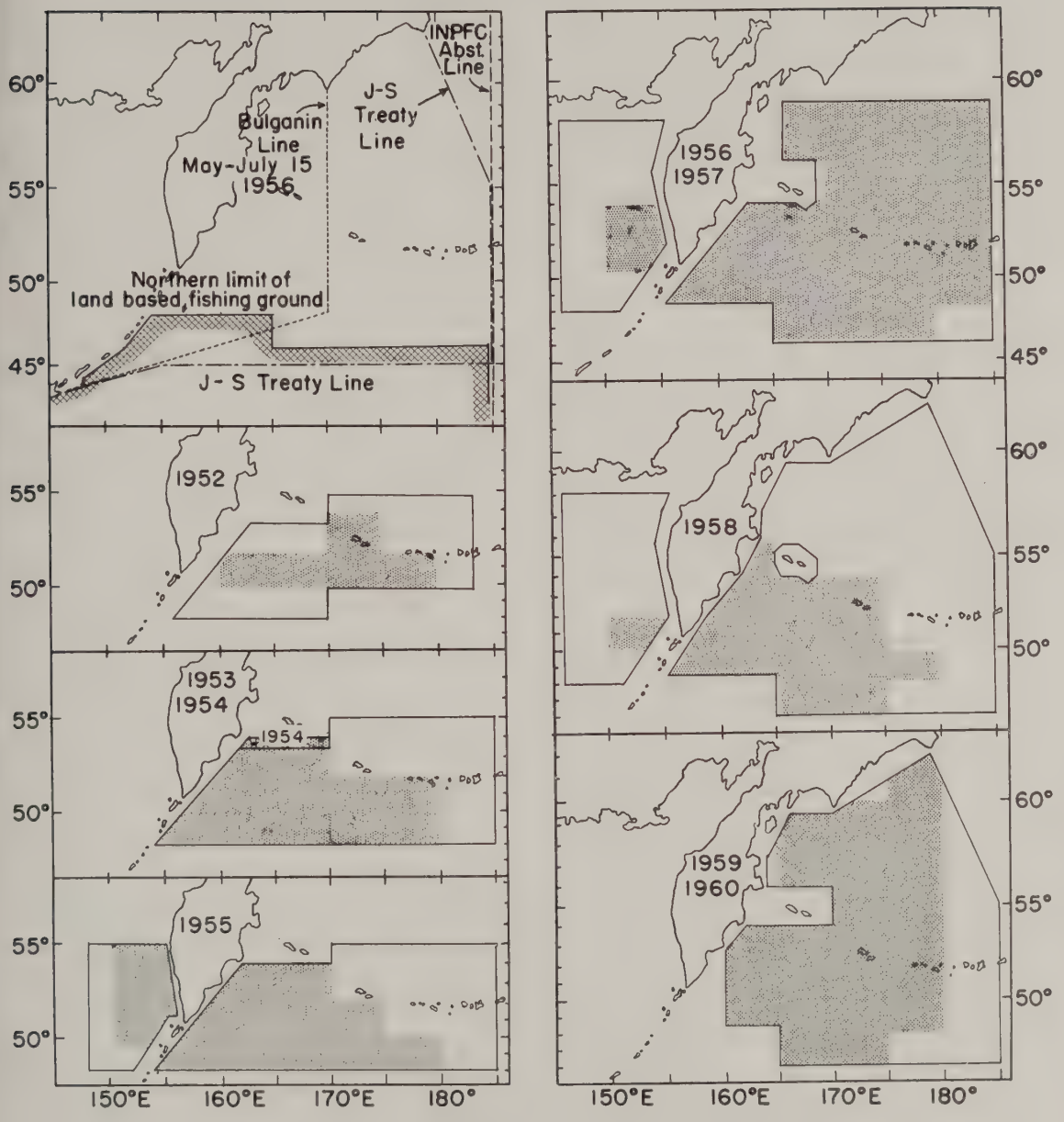

FIGURE 2. Japanese high seas commercial salmon fishing grounds, 1952–1960.

in both the Bering Sea and south of the Aleutians. A further change south of the Aleutians included the extension of the southern boundary east of Longitude 165°E from Latitude 48°N to 46°N. In 1956 only, in accordance with regulations resulting from Japan-Soviet treaty negotiations, fishing prior to July 15 was restricted to waters east of Longitude 170°E. In the years to follow in the North Pacific and the Bering Sea the permissible fishing areas remained unchanged, although no fishing was conducted in the Bering Sea in 1958. Fishing in the Okhotsk Sea was reduced from two fleets to one in 1958, and was discontinued in 1959.

The seasonal movement of the mothership fleets and the fishing periods in the three major regions in

general have been rather similar in the different years (Table 2). The fleets left Japan during May, proceeded rapidly eastward to waters south of the western Aleutians, arriving there after mid-May. After a few weeks of fishing in these waters the fleets would either gradually approach the southeast coast of Kamchatka, reaching there in July and remaining usually into August, or split into two groups, one moving into the Bering Sea, the other remaining in the North Pacific. Operations in the Bering Sea usually commenced during mid-June and terminated during late July.

In the Okhotsk Sea, the fleets usually arrived in early June. Their withdrawal ranged from late July (1957) to mid-August (1955).

Several changes have occurred in the construction of the gillnets fished. Initially, gillnets were made from ramie and contained meshes which measured 5.1", diagonal stretched measure. In 1954, nylon gillnets of similar mesh size were introduced and fished together with ramie gillnets, with nylon predominating. In 1955 and in subsequent years, nylon gillnets completely replaced ramie gillnets since they proved to be more efficient and practical. Also, in 1955, mesh sizes were reduced from 5.1" (130 mm) to 4.8" (121 mm), with the expectation that the smaller meshes would be more effective in catching pink salmon as well as sockeye and chum salmon. From 1956 to 1959, gillnets having 4.8" webbing only were used. In 1960, as a result of Japan-Soviet fishery treaty negotiations, some reversion was made towards larger meshes, with 25% of the gillnets being 5.1" mesh.

In addition to changes in mesh size, the length of a tan of gillnet increased. In 1952, a tan measured 158 feet along the corkline; in 1953, 170 feet; in 1954 and thereafter, usually 180 feet. In 1957, the maximum length of gillnet officially permitted individual catcher boats was 15 kilometers (49,170 feet).

Annual Catch and Effort.

The annual total catch and total effort for mothership operations for the years 1952–1960 are given by major region in Table 3.

The North Pacific Ocean, compared with the Okhotsk Sea and Bering Sea, was by far the most important fishing region. In years when fishing was conducted in the three regions at least 68% of the total salmon catch was from the North Pacific.

The catch in the North Pacific increased annually from 2.1 million salmon (all species) in 1952 to 42.9 million in 1955. The increases during this period were directly related to increases in fishing effort. In 1956, in spite of still further increases in effort, catches dropped to 35.5 million salmon. This decline

TABLE 2. Fishing periods for major mothership regions, 1952–1960.

Year	North Pacific	Bering Sea	Okhotsk Sea
1952	Early May—Early August	—	—
1953	Early May—Mid-August	—	—
1954	Mid-May—Late August	—	—
1955	Early May—Late August	—	Early June—Mid-August
1956	Early May—Mid-August	Mid-June—Late July	Late June—Early August
1957	Early May—Late July	Mid-June—Mid-July	Early June—Late July
1958	Mid-May—Early August	—	Early June—Early August
1959	Late May—Late July	Late June—Late July	—
1960	Late May—Early August	Early June—Mid-July	—

TABLE 3. Total catch and effort for mothership operations, by region and by year, 1952–1960.

	North Pacific		Bering Sea		Okhotsk Sea	
Year	1,000's of fish	1,000's of tans	1,000's of fish	1,000's of tans	1,000's of fish	1,000's of tans
1952	2,091	471	—	—	—	—
1953	7,682	1,345	—	—	—	—
1954	20,424	3,308	—	—	—	—
1955	42,950	7,017	—	—	12,235	696
1956	35,507	7,209	5,594	2,102	9,367	470
1957	41,051	5,206	9,452	1,407	9,873	539
1958	45,725	8,323	—	—	4,076	393
1959	31,141	5,539	11,190	1,557	—	—
1960	18,413	4,633	8,015	1,885	—	—

was largely due to the inability of the mothership fleets, as a result of the implementation in that year only of the Russian Edict (Bulganin) Line, to continuously exploit the major salmon concentrations during their westward migration. In 1957, catches were considerably higher than in 1956 even though the fishing effort had dropped by about one-quarter. In 1958, catches and effort were both maximal, principally because all fleets remained within the North Pacific instead of some units deploying into the Bering Sea. Following 1958, catches declined, presumably mainly in response to reduced fishing effort.

The total salmon catch in the Okhotsk Sea declined from a high of 12.2 million fish in 1955 to 4.1 million in 1958. The decline during this period paralleled the annual changes in fishing effort rather closely.

The annual total catches in the Bering Sea fluctuated between a high of 11.2 million salmon in 1959 and a low of 5.6 million in 1956. The annual variations in catch did not appear to be related to annual changes in fishing effort.

Collection and Compilation of Detailed Catch and Biological Data

The catch statistics and biological data for the mothership fishery used in this report were made available by the Fisheries Agency of Japan.

The catch of each species and effort data were compiled according to statistical areas[1] of two degrees of latitude and five degrees of longitude (hereinafter referred to as statistical areas) and by early, middle and late 10-day periods[2] for each month in the following manner. The daily catch statistics for all catcher boats in each fleet were assigned to the statistical area occupied by the mothership at noon. If the reported noon position fell on a latitudinal boundary the data for that day were assigned to the statistical area to the north; if on a longitudinal boundary, the area to the east. When two or more motherships operated in the same statistical area during the same 10-day period, their catch statistics were combined.

The salmon catch by species and the number of tans fished are tabulated (in thousands) by statistical area and 10-day period for each year from 1952–1960 in Appendix Table D. For each species, catches exceeding 500 fish were rounded up to the next thousand.

Appendix Table D for the years 1952, 1953 and 1954 includes statistics for scout boats as well as catcher boats. During these years some of the scout boats on occasion operated beyond the statistical area occupied by their mothership, and accordingly the recorded catch and effort for that area are in excess of the actual quantities. It is believed, however, that the discrepancies arising from this source are small. During 1955 and 1956, the scout boats ranged over a wider area, some as much as several hundred miles from their motherships, but their catches are not included in the statistics. Instead, statistics for catcher boats only are given. The exclusion of scout boat data for these two years reduces the reported total salmon catch by approximately nine million fish in 1955 and two million fish in 1956. In 1957 and in subsequent years, scout boats operated closer to their motherships, and accordingly their catches were included with those of catcher boats. The error arising from this practice is believed negligible.

Mothership catches were first sampled for biological data in 1952 and sampling continued unsystematically each year through 1955. Except for the ages of chum salmon caught in 1955, data collected during these years are not considered sufficiently reliable or complete to warrant their analysis and presentation at this time. In 1956, a sampling program was established and sampling was carried out on a large scale by Japanese Fisheries Agency inspectors stationed aboard each mothership. Each day, 30 sockeye salmon were sampled on each mothership, 30 chum salmon on one-half of the mothership fleet and 30 pink salmon on the other half. For each fish sampled, the fork length, body weight, gonad weight and sex were recorded and a scale sample was obtained. In 1957, the sampling program was expanded to include 30 sockeye, 30 chum, 30 pink, 10 coho and 10 chinook salmon, daily, and scales were taken from all fish of each species except pink salmon. For pink salmon, scales were obtained from 10 of the 30 fish sampled.

As a result of the scale sampling, age data are available for sockeye from 1956, for chum salmon from 1955

[1] The statistical areas fished by research vessels were combined into 10 regions and those fished by Japanese commercial vessels, including mothership and landbased areas, into six regions (Figures 1 and 2). The commercial fishery regions were predetermined by the Fisheries Agency of Japan. The research vessel regions were arbitrarily established with the intent to subdivide the North Pacific and the Bering Sea into regions of approximately equal width. For these reasons the boundaries for the two sets of regions do not coincide. Since no attempt is being made to directly compare the results of these two operations, the differences in the location of the respective boundaries would appear unimportant.

[2] Research and commercial vessel data for each month have been divided into three 10-day periods: 1–10 (early), 11–20 (mid), 21–30 or 31 (late). Exceptions include research vessel data for May and September and biological data for mothership operations which were combined according to month.

to 1960 (except for a few samples which are known to be deficient), for coho salmon for 1959 and 1960 and for chinook salmon for 1960.

C. Japanese Research Vessels Operating in the Landbased Region

The landbased fishery area includes waters off the east coast of Hokkaido and northern Honshu directly south of the mothership area eastward to approximately Longitude 175°W (Figure 3). However, landbased vessels, while annually tending to fish further offshore, have never fished close to the eastern boundary. The southern boundary is not fixed but changes annually and seasonally, shifting northward with the availability of salmon. Several descriptions of the development and pursuance of this fishery are available (Atkinson, 1954; Nakatsu, 1960; Research Institute for the Economics of Agriculture and Forestry, 1960).

The number of vessels and the salmon catch by species (in metric tons) for the period 1952–1960 are given in Table 4. The catches were large, especially in the years following 1954, even though the number of fishing vessels was considerably smaller. The total catch during the period 1955–1960 ranged from a minimum of 41.6 thousand metric tons in 1956 to a maximum of 72.2 thousand metric tons in 1959. Considering only the three major species in terms of numbers of fish and using the average weight of pink salmon as 3.0 pounds; sockeye salmon, 4.5 pounds; chum salmon, 5.0 pounds, the catch in each of these two extreme years was estimated to be 28.6 and 44.5 million fish, respectively. Comparing these catches with the total mothership catch in the North Pacific region (Table 3), the landbased fishery catch in 1956 amounted to approximately 75% of the total mothership catch and exceeded it by about 40% in 1959.

Detailed catch and effort statistics for the landbased fishery by time and area are not available from which to study the distribution and relative abundance of salmon. Biological data based on sampling commercial catches are also lacking. Instead, information on the relative abundance and age of salmon in this region was obtained by research vessels operated by the Hokkaido Prefecture and by Japanese fishing training vessels participating in the Japanese salmon research programs. In 1956, one research vessel and one training vessel were used. During 1957 to 1960, in addi-

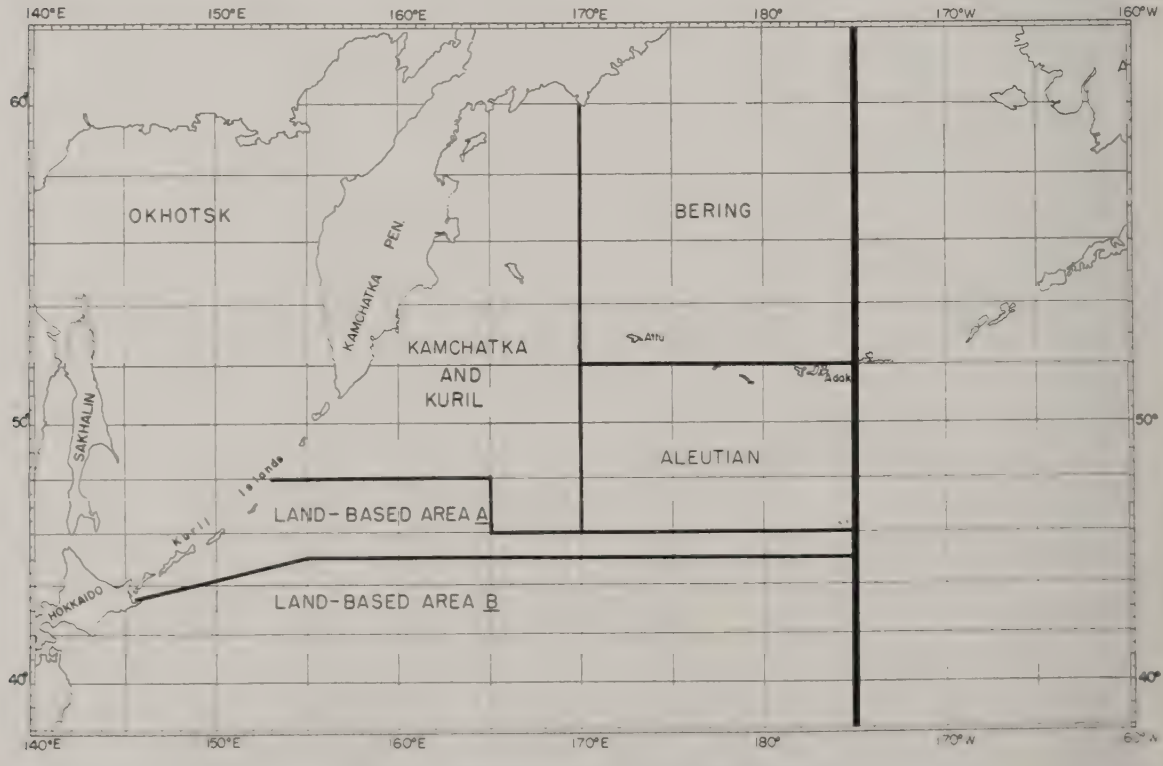

Figure 3. Japanese high seas salmon fishing regions.

TABLE 4. Number of vessels fishing in the landbased region and catch by species (in metric tons), 1952–1960.

Year	No. of vessels	Species				
		Sockeye	Chum	Pink	Others	Total
1952	1,497	—	1,834	21,765	—	23,599
1953	1,932	—	3,956	15,041	—	18,997
1954	1,897	—	7,121	14,880	—	22,001
1955	1,242	792	9,589	35,491	1,196	47,068
1956	510	228	5,644	35,536	217	41,625
1957	490	765	7,948	39,356	1,345	49,414
1958	452	1,361	19,591	36,256	2,171	59,379
1959	430	1,275	19,366	48,302	3,272	72,215
1960	415	2,454	19,070	28,080	3,881	53,485

tion to the Prefectural vessel, either three or four training vessels were employed. In each year these vessels surveyed the important commercial areas.

As far as was practicable, all salmon were sampled for age. Also, the sex, fork length, gonad weight and body weight were recorded daily for 30 sockeye, 30 pink, 30 chum, 10 coho and 10 chinook salmon.

Fishing was conducted with gillnets which varied somewhat from those used in mothership operations. The web measured 4.5″, diagonal stretched measure, mainly, but 4.65″ and 4.80″ meshes were also used. The individual tans ranged from 120 to 180 feet in length along the corkline.

IV. TREATMENT OF DATA

The sources and kinds of data used in the study of the distribution and relative abundance of salmon have been described in the previous section. Since these data were obtained from several sources and compiled in different ways, depending upon the source, the methods of treating the data, of necessity, varied. This section describes the methods used in treating the catch statistics and biological data for each species.

A. Relative Abundance Indices

Changes in the relative abundance of each salmon species were determined from catch per unit of effort (CPUE) indices for commercial and research vessel operations. The index for each source dealt with data on a 10-day basis in order to detect the rapid changes in distribution which could be expected from the dynamic nature of salmon migrations, particularly where maturing individuals were concerned. The method of computing indices for the respective operations differed in accordance with the gear used by each.

Since mothership operations used one mesh size only (4.8″) relative abundance indices for each species except chinook salmon were simply computed on a catch per tan (180 feet or approximately 55 meters) basis for each statistical area and 10-day period. For chinook, because of smaller catches (see Appendix Figure D), the relative abundance index was taken as catch per 10 tans of gillnet.

The method for computing the relative abundance index for research vessels was not as direct as that used for mothership operations, because the former vessels fished with varying numbers of different mesh-sized gillnets. Instead, the index represented a catch weighted to 3,000 feet of gillnet (approximately 915 meters), each mesh size given equal weight (Appendix Figure B). If more than one fishing operation, regardless of country, was made in any statistical area within the 10-day period, the weighted catches were averaged to provide an index. Although the gillnets used by each country did not include the same mesh sizes in every year (standardization of gillnets was innovated in 1957), and the recording of catches by mesh size was not complete in all instances, it is felt in the face of other variables that the relative abundance indices in the different years are reasonably comparable.

Indices for June, July and August were computed on a 10-day basis. Earlier and later periods were each represented by single indices. This system applied to all species but chinook salmon. Because of small catches of this species, indices were computed on a monthly basis.

In most years, Japanese research vessels, in addition to fishing with INPFC gillnets, also used varying quantities of commercial gear. The catch per tan values computed for these commercial gillnets are shown in Appendix Figure D, for the appropriate time periods and areas. No attempt was made to attach any quantitative value to these indices since, as will be shown in Section V, relative abundance indices derived from commercial vessels and research vessels using the commercial gear are not directly

comparable. These indices, for the purpose of this report, are valuable mainly for showing the presence or absence of salmon.

For descriptive purposes, the indices derived from mothership and research vessel data were grouped into four categories, representing different levels of relative abundance, as follows:

	Index range	
Abundance level	*Mothership (catch/tan)*	*Research vessel (weighted catch/3,000 ft)*
Low	0.1–1.0	1–10
Medium	1.1–2.0	11–20
High	2.1–3.0	21–30
Very high	over 3.0	over 30

In considering the distribution and relative abundance of each species, CPUE indices for mothership and research vessels were treated independently. This treatment was necessary since the indices for these operations were obtained from catches made by gillnets differing in mesh size complement. Other features, such as fishing abilities, fishing objectives, etc., must also affect the catches of the two operations. Therefore, the two sets of indices are not directly comparable.

B. Biological Data

Maturity

Maturing fish were considered to be individuals which would have spawned in their year of capture and immature fish those which would have spent one or more winters at sea. Because habits and movements of maturing and immature salmon differ, these two groups were treated separately. Separation was done using methods developed by Ishida and Miyaguchi (1958), Takagi (1961) and Godfrey (1961) based on gonad and body weight data. Although these methods differed to some extent, the conclusions were similar.

Age, ocean residence, size of fish and season are also useful in separating maturing from immature salmon, but because of variations between individual salmon these characters in general are less reliable, considering the many different life-history types, growths and spawning habits. In some instances where gonad data were unavailable, the above features were used to provide supplementary information.

The gonad weight methods have been applied only to sockeye and chum salmon caught by commercial and research vessels. All pink salmon had completed one winter in the ocean and therefore were maturing fish. Most of the coho salmon had spent at least one winter at sea, and also were considered to be maturing. No attempt was made to separate chinook salmon according to stage of maturity.

For sockeye and chum salmon, the proportions of immature and maturing fish are expressed by the percentage of immature individuals. For research vessels, this percentage value was obtained from the weighted catches for the same time periods and areas used in the computation of relative abundance indices. The percentage values for immature fish are shown in Appendix Figure B above the symbols representing the relative abundance indices. For commercial vessels the maturity data are given on a monthly and regional basis.

Ages of Salmon

Method of Recording Age.

Because of different life-history types within and between species, the distribution of fish of different ages has been considered according to total age, and ocean age as well in the case of sockeye and coho salmon. The method of recording ages for the various species follows.

Sockeye, coho and chinook salmon. Since freshwater and ocean residence are normal for these species, these life history periods were indicated by adopting the Gilbert system of recording ages. A 4_2 fish therefore was interpreted as being caught in its fourth year of life, either as a maturing or immature individual after having spent one complete growing season in fresh water, migrated down to the ocean early in its second growing season, and spent two winters in the ocean. A fish of this age may also be described as a 1-year-freshwater and 2-winter-ocean fish.

Chum and pink salmon. The young of these species, upon emerging from the gravel, immediately migrate to sea, thus remaining in fresh water only the length of time required to reach the estuaries. The ages of these species were determined from the number of winters spent at sea. A 3-year-old chum salmon therefore is one which has completed two winters in the ocean. The pink salmon caught, because of their life history and the gear used, were all in their second year, having spent one winter in the ocean.

Agreement in Age Determinations by Canada, Japan and the United States.

The ages of salmon used in this report were those determined by each national Scale Reading Group reading scales collected by the respective high seas fishing groups. It is not proposed to review here the

TABLE 5. Agreement in age readings of sockeye and chum salmon by Scale Reading Groups of Canada, Japan and the United States.

Species	Sample source	Sample size	Agreement	Disagreement	Percent agreement
SOCKEYE					
Total age	Northwest Pacific				
	1958	211	123	88	58.3
	1959	212	173	39	81.6
	Total	423	296	127	70.0
	Northeast Pacific				
	1957	342	272	70	79.5
	1958	174	147	27	84.5
	Total	516	419	97	81.2
SOCKEYE					
Ocean age	Northwest Pacific				
	1958	211	196	15	92.9
	1959	212	203	9	95.8
	Total	423	399	24	94.3
	Northeast Pacific				
	1957	342	332	10	97.1
	1958	174	173	1	99.4
	Total	516	505	11	97.9
CHUM					
	Canada	94	75	19	79.8
	Japan	97	86	11	88.7
	Alaska	117	92	25	78.6
	Total	308	253	55	82.1

problems associated with establishing criteria for determining the ages of salmon. It must suffice to say that the scale pattern of individual salmon within a species can differ, that the differences between individual scale patterns can be quite marked and that, in some instances, the scale pattern can be characteristic of a specific stock.

Since research vessels of each country caught salmon over vast ocean areas (see Appendix Figure A), it is unlikely that all scales examined by each Scale Reading Group were aged with equal facility. While ease of age determination of individuals within populations is known to be variable, scales from " foreign " fish with uncommon or relatively unfamiliar life-history types presumably would present greater difficulty to any Scale Reading Group reading these scales than would scales from indigenous populations. In some instances, as a consequence, this varying familiarity of each Scale Reading Group with the scale patterns of all North Pacific salmon stocks could result in differences in interpretation of scale patterns, and hence differences in age determination.

To assess the extent of agreement in age determination for sockeye and chum salmon, the same scale samples collected from widely separated areas were submitted to each Scale Reading Group for reading. The sockeye samples represented fish caught in the western North Pacific in 1958 and 1959 and from the eastern North Pacific in 1957 and 1958. The chum salmon samples were from coastal collections made in Japan, Canada and Alaska in 1955. The percentage agreement between the three Scale Reading Groups in the age determinations of salmon forming the various samples of these two species is summarized in Table 5.

For sockeye, the percentage agreement among the three Scale Reading Groups was high. Agreement was higher, however, for ocean age than for total age. The average percentage agreement in total age and ocean age for all samples combined was 76.1% and 96.3%, respectively. It is apparent then that most of the difficulty in aging sockeye occurs in the interpretation of the freshwater zone.

Differences in the percentage agreement also were noted between the western and eastern North Pacific samples. Although these differences were minor,

agreement in ages of sockeye caught in the western Pacific was not as high as for sockeye taken from the eastern Pacific.

Also, the percentage agreement in the readings of total age of sockeye varied between samples taken in different years. Regarding the western North Pacific samples for 1958, mutual agreement was reached for only 58.3% of the scales examined. In the samples for 1959, agreement was very much higher, 81.6%.

For chum salmon, the percentage agreement on age of fish in the samples from Alaska, Canada and Japan ranged between 78.6% and 88.7%. Highest agreement (88.7%) was achieved in the scale samples collected from Japan. Agreement in age determination for samples from Canada and Alaska was similar (78.6% and 79.8%).

Thus, in general, the ages of sockeye and chum salmon determined by the national Scale Reading Groups, regardless of the location of the sample, are sufficiently consistent to warrant acceptance. The levels of agreement are considered high, particularly since three independent Scale Reading Groups were involved. For sockeye, the percentage agreement in ocean age is higher than in total age.

Tests of the reliability of age readings for pink, coho and chinook salmon have not been made. Since pink salmon, for practical purposes, can all be regarded as having a two-year life cycle, no problem exists in obtaining information on age of individual fish. For chinook and coho salmon, however, the findings for sockeye may well apply.

The age data available for research and mothership operations and the treatment of these data differed. Research vessel data included sockeye and chum salmon only. The ages of these fish were expressed as weighted numbers caught by 3,000 feet of gillnet, with each mesh size given equal weight, and were combined by month and statistical area. Mothership data included sockeye, chum, coho and chinook salmon. For each species, each age group was expressed as a percentage of the total sample collected, by month and region in the different years. Chum salmon data are for 1955–1960; sockeye salmon data for 1956–1960; coho salmon data for 1959 and 1960; chinook salmon data for 1960. Sockeye and chum salmon data for the period 1956–1958 were further divided into statistical areas and selected 10-day periods.

Length and Sex Ratio

Fork lengths and sex ratios of salmon were examined in a superficial manner using mothership data only. The data were available for each age and sex on a regional and monthly basis for 1957–1960.

V. RELIABILITY OF RELATIVE ABUNDANCE ESTIMATES

Gillnet catches made by the mothership fishery and research vessels are used to determine the relative abundance estimates of the various species of Pacific salmon. Since these catches are samples, they are subject to sampling error. Error or bias might result from the selectivity or varying catch efficiency of the nets. Gillnets are known to be selective; fish of a limited size range are taken by a particular mesh size. Also, the numbers of fish caught are variable. Accordingly, the efficiency or selectivity of the gillnets used and the variability in their catches need to be assessed. This assessment follows.

A. Gillnet Mesh Selectivity

A study of gillnet selectivity and its effects has been made, with two objectives: (1) to evaluate bias produced in catch per unit of effort by individual mesh sizes and combinations of mesh sizes and (2) to estimate actual size composition of a population, adjusting for effects of mesh selection.

To evaluate bias and to estimate actual size composition of a population, the essential key is to develop a gillnet mesh selection curve. Once a mesh selection curve is obtained, it can be used to estimate actual size composition as well as actual sex ratio and age composition.

A method for determining mesh selection curves (also called "catch efficiency curves") was first developed and described by Holt (1957), following to some extent work by Baranov (1948). Holt assumed the normal distribution for his mesh selection curves. Holt used the ratio of the numbers of fish of the same size class caught by gillnets of different mesh sizes, used simultaneously and in equal number, to determine the curve. Olsen (1959) modified Holt's method by using a skewed rather than the normal curve when studying Newfoundland herring. McCombie and Fry (1960) used the ratio of fish girth to mesh perimeter to develop normal mesh selection curves for Lake Huron whitefish. Garrod (1961) used selected ranges of fish lengths to develop normal curves for *Tilapia*. Gulland and Harding (1961) obtained asymmetrical curves for the atypically-shaped catfish, *Clarias*. Peterson (1964) used selected ranges of fish lengths for developing normal curves for sockeye, chum and pink salmon from the high seas of the North Pacific Ocean.

Ishida (1961, 1962) used a mesh-size ratio method for developing skewed selectivity curves for sockeye and pink salmon from the North Pacific.

In the present study, gillnet catches from four different mesh sizes fishing simultaneously from research vessels are used to develop mesh selection curves for sockeye, chum and pink salmon. Supplementary catch data on pink salmon from the Japanese training vessel *Oshoro-maru* (Hokkaido University, Faculty of Fisheries, 1958) are also used.

Method of Obtaining the Mesh Selection Curve

Let l stand for body length of fish and d stand for mesh size of gillnet. Express the catch efficiency of l by d by the term $E(l:d)$. Introduce a constant factor, k. Then, if $E(l:d)=E(kl:kd)$ is correct (basic assumption), the relative catch efficiency of various l's by any d can be obtained by using the catch (C) of various d's operating simultaneously, as follows:

Say the catches of salmon of the i^{th} size class (C_i) by d_j mesh sizes ($j=1, 2, 3, \ldots n$) are C_{i1}, C_{i2}, $\ldots C_{in}$. Assume that C_{ij} is proportional to $E(l_i:d_j)N_i$, where N_i is the available number of fish of l_i size in the population. Using d_1 as the standard (any mesh can by chosen as the standard),

$$\frac{C_{ij}}{C_{i1}} = \frac{E(l_i:d_j)N_i}{E(l_i:d_1)N_i} = \frac{E(l_i:d_j)}{E(l_i:d_1)}.$$

A series of relative efficiencies for the respective mesh sizes on i^{th} size class is represented by:

$$\frac{E(l_i:d_1)}{E(l_i:d_1)}, \frac{E(l_i:d_2)}{E(l_i:d_1)} \cdots \frac{E(l_i:d_n)}{E(l_i:d_1)}.$$

Using the assumption, $E(l:d)=E(kl:kd)$, the series can be expressed by:

$$\frac{E(l_i:d_1)}{E(l_i:d_1)}, \frac{E(l_id_1/d_2:d_1)}{E(l_i:d_1)} \cdots \frac{E(l_id_1/d_n:d_1)}{E(l_i:d_1)}$$

the relative catch efficiency of d_1 mesh on body lengths, l_i, l_id_1/d_2, $\ldots l_id_1/d_n$. A series of relative catch efficiencies of d_1 mesh on n sizes of fish is the result. When four mesh sizes are fished, $n=4$ and the curve is described by four points. This procedure is repeated for each size class of fish.

To obtain a composite mesh selection curve for all size classes of fish caught by a particular mesh size, the relative catch efficiencies for each series must be combined. An adjustment is necessary before this can be done, because the relative ordinate heights vary between series. Each series has an unknown constant, A_i, common within series but not between series. To make the adjustment, the values of each series are plotted on individual transparent sheets using a logarithmic scale on the ordinate. By using the logarithmic scale, the constant multiplying factor, A_i, becomes an additive factor. The sheets are superimposed by shifting up and down until the points on them form one smooth imaginary curve. A curve is fitted, and after transforming back from the logarithmic scale, this curve represents the selection curve for the mesh size.

Mesh Selectivity Curves for Salmon

The size composition data used to obtain estimated mesh selectivity curves for sockeye, chum and pink salmon are given in Tables 6 and 7. In Table 6, the size composition of catches of sockeye, chum and pink salmon taken by 2 1/2″, 3 1/4″, 4 1/2″ and 5 1/4″ mesh sizes of net used by research vessels (1957, *Paragon* and *Pioneer;* 1958, *Attu* and *Pioneer;* 1959, *Kano-maru*) is given by mesh size. In Table 7, the size composition of pink salmon catches by the *Oshoro-maru* in 1957, fishing with 3″, 3.8″, 4.2″, 4.8″, 5″ and 5.4″ mesh sizes of net, is given. The catch figures shown in the tables have been weighted to equalize effort for the various mesh sizes.

Sockeye Salmon.

The estimated selectivity curve of the 4 1/2″ mesh size for sockeye salmon is shown in Figure 4. To develop this curve, 21 length classes between 41 cm and 61 cm were used. Within this range of length classes, the relative efficiency values closely followed a similarly shaped curve. The curve has a mode at 51 cm to 52 cm, and the slope at the left side of the mode is steeper than the trailing right side. When a logarithmic scale is taken along the abscissa, the curve approaches a normal curve similar to one shown by McCombie and Fry (1960) for lake whitefish.

Ordinate values based on sockeye salmon lengths ranging below 38 cm did not fall along this estimated curve (Figure 5). A curve derived from length classes below 38 cm has a mode at almost the same part of the curve as that derived from the larger fish. However, the slope at the left side of the mode of the curve derived from small fish is much steeper. This difference in slope may be due to girth/length differences between small fish and large fish. Small fish have a lower girth/length relationship than large fish. A lower girth/length relationship has been shown for immature than for maturing sockeye salmon (Lander, 1963). Fish below 38 cm in length are practically all immature salmon, whereas the larger fish are both immature and maturing salmon.

A combined selectivity curve for sockeye salmon, with four different mesh sizes of standard INPFC gillnet used in equal quantity and the individual selectivity curves for each mesh size are illustrated in Figure 6. It is shown that sockeye salmon ranging between 27 and 70 cm in fork length are efficiently caught when these four mesh sizes are used together. Sockeye larger than 70 cm can be caught by these nets, but less efficiently. Sockeye less than 26 cm in length could hardly be caught. When the curve is projected to sockeye ages, 1-winter-ocean sockeye and 3-winter-ocean sockeye can be caught with almost equal ef-

TABLE 6. Length frequency distribution of salmon caught by $2\frac{1}{2}''$, $3\frac{1}{4}''$, $4\frac{1}{2}''$ and $5\frac{1}{4}''$ mesh gillnets, each mesh size given equal weight. (Data source: 1957—*Paragon*, *Pioneer*; 1958—*Attu*, *Pioneer*; 1959—*Kano-maru*.)

Fork length (cm)	Sockeye				Chum				Pink			
	$2\frac{1}{2}''$	$3\frac{1}{4}''$	$4\frac{1}{2}''$	$5\frac{1}{4}''$	$2\frac{1}{2}''$	$3\frac{1}{4}''$	$4\frac{1}{2}''$	$5\frac{1}{4}''$	$2\frac{1}{2}''$	$3\frac{1}{4}''$	$4\frac{1}{2}''$	$5\frac{1}{4}''$
22	2	—	—	—	—	1	—	—	—	—	—	—
23	1	1	—	—	1	—	—	—	—	—	—	—
24	2	1	—	—	—	—	—	—	—	—	—	—
25	7	—	—	—	—	—	—	—	—	—	—	—
26	13	—	—	—	—	—	—	—	—	—	—	—
27	34	3	—	—	7	—	—	—	—	—	—	—
28	75	—	—	—	55	—	—	—	—	—	—	—
29	137	2	1	—	180	—	1	—	—	—	—	—
30	267	5	2	1	456	6	1	2	—	—	—	—
31	281	6	—	—	185	16	1	2	—	—	—	—
32	266	18	—	1	527	61	—	6	—	—	—	—
33	166	76	9	1	327	116	1	6	—	—	—	—
34	103	145	2	1	115	105	—	—	—	—	—	—
35	54	215	3	1	57	105	1	—	—	1	—	—
36	89	199	5	3	7	82	—	2	—	3	—	—
37	25	194	1	1	6	54	—	2	—	1	—	—
38	4	143	3	—	2	60	1	—	—	10	—	—
39	16	132	5	—	3	74	—	2	—	25	1	—
40	16	120	7	—	4	85	1	—	—	51	5	—
41	—	110	7	—	4	132	1	4	—	105	11	—
42	1	112	28	1	—	140	4	4	—	209	54	3
43	—	121	57	6	1	127	13	6	2	199	144	10
44	—	105	119	3	2	122	29	4	3	205	305	12
45	1	111	177	16	3	91	46	—	4	158	363	19
46	—	93	190	11	1	55	76	6	2	91	358	29
47	6	80	234	8	5	57	91	12	3	46	349	20
48	1	63	249	30	—	28	103	32	8	30	249	56
49	—	62	246	39	1	34	127	20	2	9	209	64
50	5	29	236	46	1	15	121	24	1	2	135	55
51	13	21	179	55	—	11	131	36	2	6	66	55
52	2	22	164	73	1	8	120	44	—	1	33	33
53	27	10	148	79	1	11	120	52	3	5	33	28
54	1	7	91	93	1	22	120	83	—	—	10	13
55	2	7	75	76	1	7	114	99	1	2	8	14
56	7	4	55	54	—	5	87	104	—	1	1	5
57	4	5	45	62	—	4	81	88	—	—	1	3
58	2	7	37	49	—	7	56	71	—	—	1	1
59	1	7	24	40	2	4	33	58	—	—	—	—
60	3	1	19	38	—	2	36	57	—			
61	1	1	13	26	—	1	28	35	—	—	—	—
62	—	3	12	24	—	2	24	35	—	—	—	—
63	—	3	10	10	—	—	12	28	—	—	—	—
64	—	3	6	10	—	1	5	24	—	—	—	—
65	3	5	6	7	2	—	7	13	—	—	—	—
66	—	—	6	10	—	—	5	9	—	—	—	—

TABLE 7. Length frequency distribution of pink salmon caught by gillnets of various mesh sizes, each mesh size given equal weight. (Data source: 1957—*Oshoro-maru*.)

Fork length (cm)	Mesh size					
	3″	3.8″	4.2″	4.8″	5″	5.4″
36.5	1	—	–	—	—	—
37.5	—	1	—	—	—	—
38.5	2	5	1	—	—	—
39.5	4	4	8	—	—	1
40.5	10	35	25	2	—	2
41.5	15	76	54	7	—	2
42.5	21	130	153	15	2	2
43.5	23	126	181	26	2	4
44.5	10	106	189	50	3	5
45.5	7	50	131	58	3	4
46.5	5	37	94	49	10	3
47.5	—	23	54	37	3	5
48.5	—	21	23	23	10	3
49.5	—	24	11	10	6	4
50.5	—	20	6	8	5	4
51.5	—	14	3	5	3	—
52.5	—	5	—	2	2	2
53.5	—	5	—	—	2	1
54.5	—	—	—	—	2	—
55.5	—	1	—	—	—	1
56.5	—	1	—	—	-	—

ficiency. The combined mesh sizes are especially efficient for sockeye between 50 cm and 60 cm, because of the close interval between the 4 1/2″ and 5 1/4″ mesh sizes. If a slightly smaller mesh size were used in place of the 4 1/2″ mesh, the combined selectivity curve would be more uniform.

Chum Salmon.

Figure 7 shows the estimated selectivity curve of the 4 1/2″ mesh for chum salmon. The points to which the smoothed curve is drawn are more scattered than in sockeye in the smaller length classes. The curve is ill-defined for fish below 46 cm. The selectivity curve for sockeye, compared in Figure 7 with the curve for chum salmon, is similar over most of its range, indicating that the two species have quite similar body shapes. The steeper slope on the left side of the curve may be due to smaller girths in chum salmon than in sockeye at these lengths.

Pink Salmon.

The estimated selectivity curve of the 4.8″ mesh for pink salmon, derived from the *Oshoro-maru* data of Table 7, is illustrated in Figure 8. This curve is almost flat on the top. This flatness is not considered meaningful, and it would be more practical to assume that this curve (with slight variation) forms a convex top. However, the intervals of mesh sizes used were too large to point out slight variations.

Figure 9 compares the selectivity curves of the 4.8″ mesh and standard INPFC gillnets. Selection by the two kinds of gillnet is similar for fish less than 55 cm. For larger pink salmon, INPFC gillnets are relatively more efficient than the 4.8″ mesh gillnets.

Selectivity of Commercial Gillnets for Age of Fish

Based on the curves of Figures 4, 7 and 8, relative efficiency values for gillnets of commercial mesh size are shown in Table 8. Values for sockeye, chum and pink salmon are shown for the 4.8″ mesh used in the mothership fishery and for pink salmon for the 4.5″ mesh used in the landbased fishery.

In order to examine the selective action of commercial gillnets on various age classes of chum, sockeye and pink salmon, length frequency distributions of fish

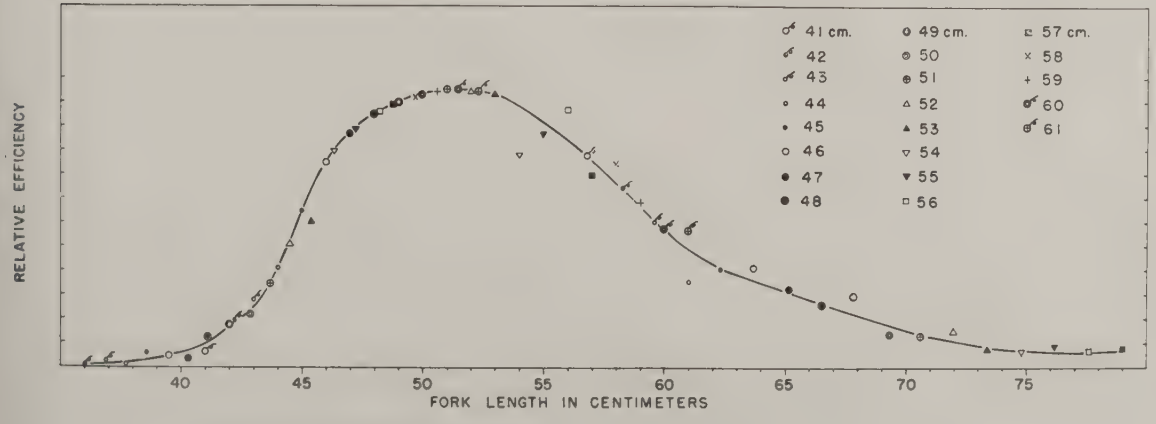

FIGURE 4. Estimated selectivity curve of the 4.5″ mesh gillnet for sockeye salmon.

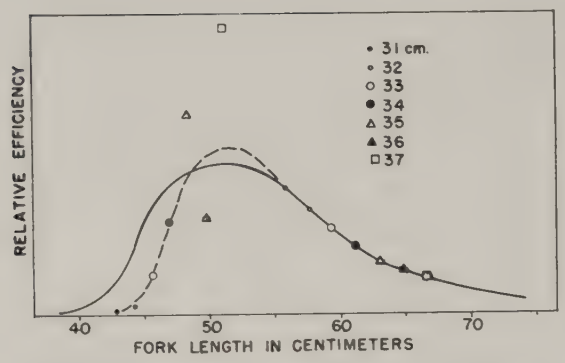

FIGURE 5. Comparison of selectivity curves of 4.5″ mesh gillnet for sockeye larger than 40 cm (solid line) and smaller than 38 cm (broken line).

of different ages caught by standard INPFC gillnets are illustrated in Figure 10. Table 8 shows the relative efficiency of commercial gillnets for fish of various lengths. Using Figure 10 and Table 8, the relative efficiency of the nets can be compared with the age of fish caught.

It is noted that the small, 1-winter-ocean sockeye salmon are scarcely caught by a net of 4.8″ mesh size. This mesh size catches 2-winter-ocean sockeye as efficiently as 3-winter-ocean sockeye. In other words, the 4.8″ mesh size is designed to catch 2- and 3-winter-ocean sockeye.

Concerning chum salmon, few 2-year-old fish are caught by the 4.8″ mesh size of gillnet. The larger

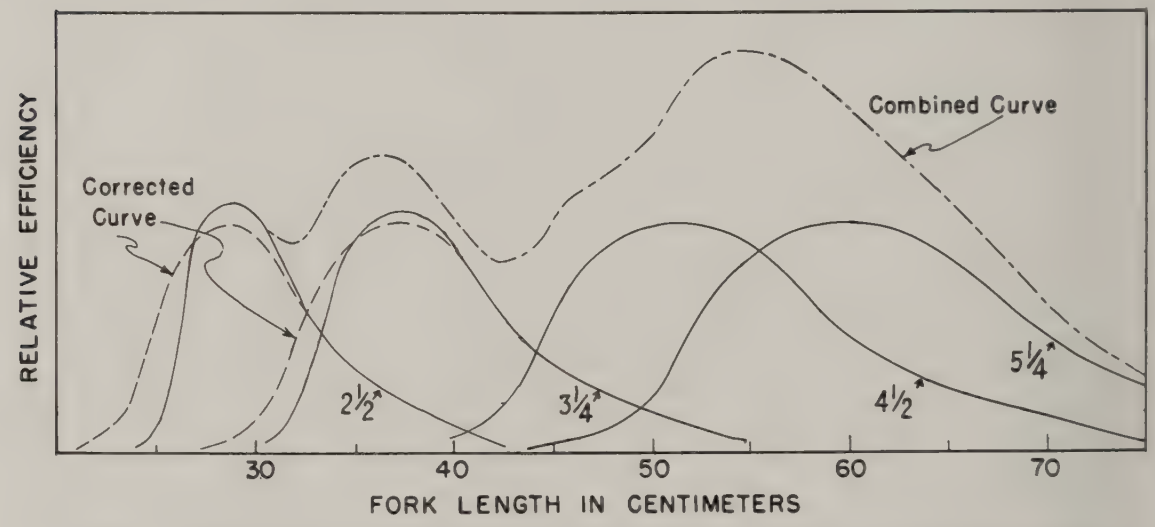

FIGURE 6. Individual and combined selectivity curves for sockeye salmon for equal numbers of standard INPFC gillnets.

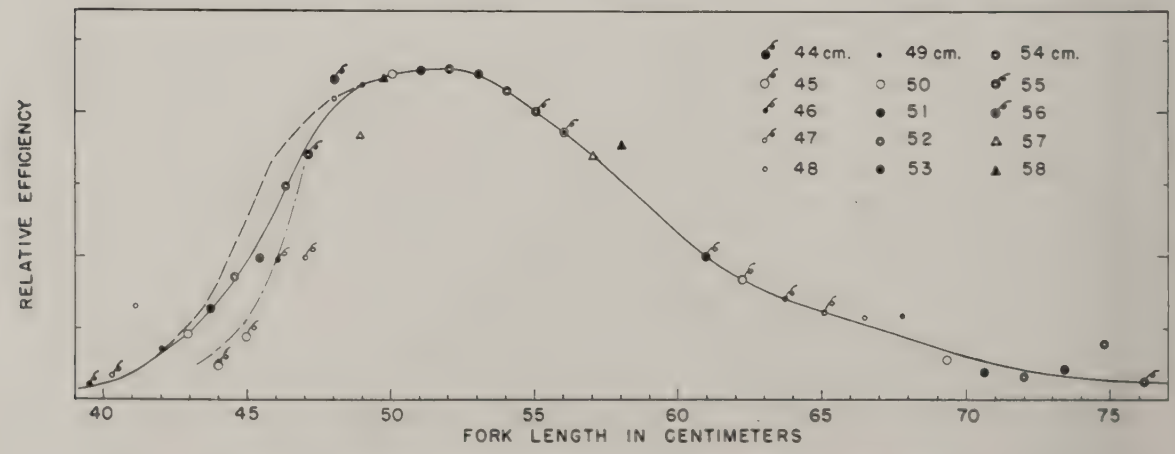

FIGURE 7. Estimated selectivity curve of the 4.5″ mesh gillnet for chum salmon.

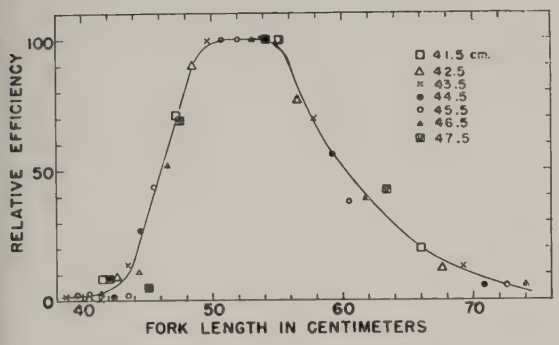

FIGURE 8. Estimated selectivity curve of the 4.8″ mesh gillnet for pink salmon.

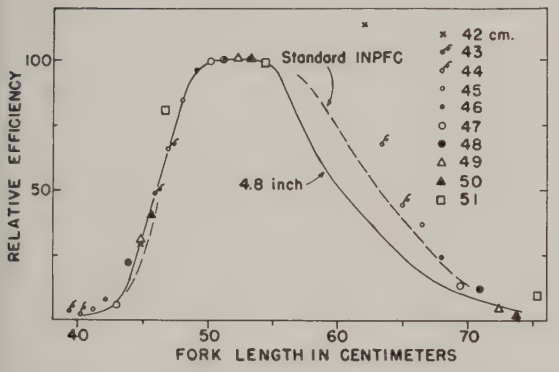

FIGURE 9. Comparison of pink salmon selectivity curves of 4.8″ (*Oshoro-maru* data) and standard INPFC gillnets.

3-year-old fish can be efficiently caught, but the efficiency for the smaller fish of this age, although not well-defined, is low. The maximum efficiency of this mesh size fits on the mode of the size distribution curve of 4-year-old chum salmon.

Regarding pink salmon, it is clear that the 4.8″ mesh size used by the mothership fishery is too large to catch pink salmon efficiently. Only the large pink salmon in late June or later would be caught efficiently.

In the landbased fishery, nets of 4.5″ mesh are designed to catch pink salmon primarily. The efficiency of the 4.5″ mesh is much higher than 4.8″ mesh. However, the 4.5″ mesh is still too large to efficiently catch the smaller pink salmon in April and May.

Concept of Mesh Size Efficiency

If the length frequency distributions of commercial catches are known, it is possible to estimate the effi-

TABLE 8. Relative efficiency of commercial gillnets for sockeye, chum and pink salmon of various lengths.

Fork length (cm)	Sockeye	Chum	Pink	
	4.8″	4.8″	4.8″	4.5″
41	3	?	2	12
42	4	?	3	29
43	7	?	5	46
44	11	?	11	64
45	18	?	25	81
46	26	24	40	97
47	43	36	57	100
48	65	49	73	100
49	83	65	89	100
50	96	86	98	100
51	104	100	100	100
52	109	108	100	97
53	112	112	100	85
54	114	114	100	74
55	115	115	99	64
56	114	114	94	55
57	110	110	82	48
58	105	105	71	41
59	100	100	63	35
60	91	91	55	30
61	83	83	48	25
62	74	74	42	—
63	66	66	—	—
64	58	58	—	—
65	50	50	—	—
66	43	43	—	—
67	39	39	—	—
68	36	36	—	—
69	33	33	—	—
70	29	29	—	—

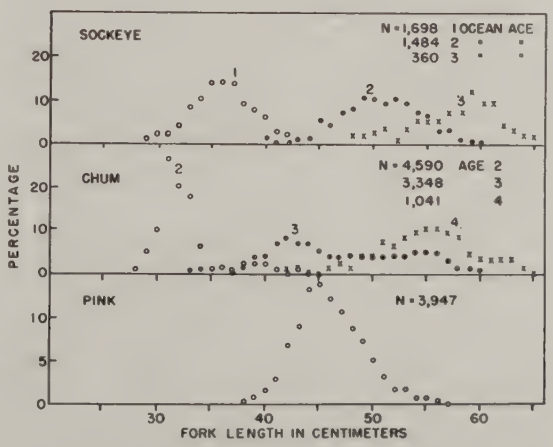

FIGURE 10. Size frequency distribution of sockeye, chum and pink salmon of different ages in catches by standard INPFC gillnets.

TABLE 9. Mesh size efficiency* of mothership gillnets (4.8″ mesh) for sockeye salmon, by region and by month, 1957–1960.

Year	Month	Region			
		East of 170°E	West of 170°E	Okhotsk Sea	Bering Sea
1957	May	0.89	0.86	—	—
	June	0.84	0.84	0.86	—
	July	0.79	0.83	0.84	—
1958	May	0.86	0.90	—	—
	June	0.84	0.84	0.64	—
	July	—	0.80	0.86	—
	August	0.81	0.73	0.73	—
1959	May	0.87	0.90	—	—
	June	0.78	0.76	—	—
	July	0.68	0.74	—	—
1960	May	0.84	0.85	—	—
	June	0.86	0.86	—	0.82
	July	0.65	0.75	—	0.82
	August	—	0.65	—	0.80

* Ratio of catch from a given mesh size to possible catch from optimum mesh size.

TABLE 10. Mesh size efficiency* of mothership gillnets (4.8″ mesh) for chum salmon, by region and by month, 1957–1960.

Year	Month	Region			
		East of 170°E	West of 170°E	Okhotsk Sea	Bering Sea
1957	May	0.84	0.84	—	—
	June	0.76	0.81	0.91	—
	July	0.68	0.76	0.91	—
1958	May	0.92	0.91	—	—
	June	0.86	0.85	0.91	—
	July	—	0.71	0.83	—
	August	0.74	0.66	0.76	—
1959	May	0.87	0.86	—	—
	June	0.83	0.83	—	—
	July	0.78	0.80	—	—
1960	May	0.90	0.88	—	—
	June	0.88	0.89	—	0.89
	July	0.68	0.83	—	0.87
	August	—	0.76	—	—

* See note for Table 9.

TABLE 11. Mesh size efficiency* of mothership gillnets (4.8″ mesh) for pink salmon, by region and by month, 1957–1960.

Month	1957		1958		1959	1960
	Aleutian & Bering Sea	Okhotsk Sea	Aleutian & Bering Sea	Okhotsk Sea	Aleutian & Bering Sea	Aleutian & Bering Sea
May	0.20	—	0.63	—	0.70	0.39
June	0.39	0.35	0.44	0.15	0.48	0.46
July	0.48	0.44	0.53	0.32	0.48	0.68
August	—	—	0.77	0.83	—	0.91

* See note for Table 9.

TABLE 12. Mesh size efficiency* of 4.5″ mesh gillnets for pink salmon in the landbased fishery region, by month, 1957–1960.

	North of J-S treaty line				South of J-S treaty line			
Year	May	June	July	August	May	June	July	August
1957	-	0.83	0.77	0.91	0.67	0.71	—	—
1958	0.67	0.63	0.83	0.91	0.59	0.63	0.91	0.83
1959	—	0.63	0.83	0.67	0.50	0.63	0.91	—
1960	—	0.77	0.91	0.91	0.10	0.35	0.56	—

* See note for Table 9.

ciency of a commercial gillnet on the salmon population available to it by referring to Table 8. This leads to proposing a new concept of mesh size efficiency of gillnets, defined as follows:

$$\text{Mesh size efficiency} = \frac{\text{Catch in a given mesh size}}{\text{Assumed catch in the optimum mesh size for salmon of all sizes}}$$

The reciprocals of these values can be used as correction factors for CPUE indices of relative abundance. These correction factors can also be used to estimate true sex ratio, age composition and size composition of the population available to the fishery.

In Tables 9, 10 and 11, mesh size efficiency of the 4.8″ mesh nets used in the mothership fishery is shown on a monthly basis for the years 1957 through 1960 for sockeye, chum and pink salmon, respectively. Table 12 shows the mesh size efficiency for pink salmon by the 4.5″ mesh nets in the landbased fishery for 1957 through 1960. The size composition data used are taken from Appendix Table G. The values of mesh size efficiency are always less than 1.0 and usually less than 0.9 for the ratio.

With sockeye salmon (excluding 1-winter-ocean fish), this value is highest in May, ranging from 0.90 to 0.84. As the season progresses the values decrease, ranging from 0.81 to 0.40 in August (Table 9). It appears that bias produced by mesh selectivity on the indices of relative abundance of sockeye is not great.

The trend in mesh size efficiency shown for sockeye is also true for chum salmon (Table 10). Chum salmon below 46 cm, including not only 2-year-old fish but also small 3-year-old fish, have been omitted. Because of this, the effects of bias from mesh selectivity on relative abundance of chum salmon cannot be properly evaluated.

Concerning pink salmon, the mesh size efficiency varies greatly between years as well as within years (Table 11). In general, the values increase as the season progresses. However, in 1958 and 1959, the value in May was larger than that in June. This anomaly may have occurred because of different populations being fished in May and June. Values are as low as 0.20 (1957) and 0.15 (Okhotsk Sea, 1958) early in the season. However, in August, the values are generally high, ranging between 0.77 and 0.91. Such extreme changes in mesh size efficiency of gillnets definitely distort relative abundance indices unless corrections are made.

In the landbased fishery, the mesh size efficiency values of the 4.5″ mesh for pink salmon, the major species, rarely drop to values less than 0.50 from May to August. The values are generally lowest in May, and increase until they reach maximum values in July or August. During the early part of the season the pink salmon are too small for the 4.5″ mesh. As the season progresses, pink salmon grow in size and the efficiency of the nets increases. In some cases, after obtaining maximum values in July, the values decrease in August, probably as a result of pink salmon becoming too large to be caught most efficiently by the 4.5″ nets. Comparing mesh size efficiency in the landbased fishery region and the mothership fishery region during June and July, values in the former region are generally larger than 0.50, but those in the latter are often smaller than 0.50. This is good evidence that the 4.5″ mesh size used by the landbased fishery fishes pink salmon more efficiently than the 4.8″ mesh size used in the mothership fishery.

To summarize, gillnet selectivity curves were developed and applied to mesh sizes used in the research vessel and mothership operations. The four mesh sizes used by research vessels appear to cover the size range in salmon adequately when given equal weight for effort. This applies to sockeye, chum and pink salmon of all vulnerable ages and sizes. No adjustment for the effects of selectivity appears necessary in the research vessel catches.

In the mothership operations, the 4.8″ mesh is selective for the larger fish. Few 1-winter-ocean

sockeye, 2-year-old chum and small pink salmon are taken. The 4.8″ mesh catches 2-winter-ocean and 3-winter-ocean sockeye and 3-year-old and 4-year-old chum salmon with relatively high efficiency. The estimates are not as clear for chum salmon as for sockeye. The mesh size efficiency for pink salmon is low, especially in the early season.

Since the selectivity effects on 2-winter-ocean and 3-winter-ocean sockeye and 3-year-old and 4-year-old chum salmon in the mothership fishery are estimated to be minor, no adjustment for bias seems necessary. Adjustment in pink salmon appears warranted and this will be considered later in Section VIII.

In the landbased fishery, the 4.5″ mesh appears to take pink salmon, the predominant species, more efficiently than the 4.8″ mesh in the mothership fishery. No adjustment for bias is deemed necessary.

B. Variability in Gillnet Catches

The relative abundance estimates and information on the compositional characters (age, maturity, length, etc.) of the catch of the various species of salmon within a statistical area during each 10-day period are based on only a very few or, frequently, on only a single fishing operation. Since the catches upon which this information was based were made under varying conditions and circumstances, the reliability of the results can vary considerably.

In the absence of experiments specifically designed to measure variability in surface gillnet catches, catches made on successive nights in the same location and others made at stations relatively close to each other on the same night were examined in order to get some information on the comparability of the catches.

Short-Term Variation

Evidence of short-term variation in the high seas catches was obtained from successive nightly catches made by Canadian research vessels operating in 1957 and 1958. The number of fishing operations in each series ranged from two to four sets. The catch, effort, percentage of immature sockeye and chum salmon and wind force according to the Beaufort scale are given for the individual sets in each series in Table 13.

The numbers of salmon caught on successive nights within a series of observations varied, even though fishing effort was reasonably constant. The size of catches within the various series varied by as much as 25 times. In most instances, however (six of nine series), the size of catches differed threefold or less.

The species composition of catches in the same location on successive nights varied. In six of nine sets of operations, there was no change in the dominant species. In only three of the nine operations, however, was the rank of the individual species unchanged.

Within a series of nightly catches, for both sockeye and chum salmon, the proportion of immature individuals was reasonably similar.

Several factors are believed to produce short-term variations in the size and composition of the catch. As can be seen from the table, wind force would appear to be important. Catches tended to be smaller when winds were stronger. Possible explanations for this effect are changes in the behaviour of salmon under varying states of the sea, which in turn may make salmon less available to capture; reduced efficiency of the gear; and the loss of fish from the gillnets during hauling. The catches for the August 2–4, 1957, series at Latitude 52°N, Longitude 145°W are somewhat anomalous. Here, under extremely variable wind velocities, catches were small. The catches in this instance are believed to be truly indicative of the abundance levels of salmon, which during August are known to be relatively low. This phenomenon will be pointed out when dealing with changes in the relative abundance of the various species.

It is possible, although conclusive evidence is lacking, that some of the nightly variation in the size and composition of the catches may be due to different migration times of maturing individuals of each species. The effect of this variation would presumably increase through the season, and from high seas to coastal areas.

Local Variation

Information on local variation in gillnet catches was obtained from Japanese research vessels operating relatively close to each other on the same night, during July and August in 1956. The number of gillnets fished ranged between 150 and 306 tans. Presumably, fishing conditions on any one night were reasonably similar and fishing abilities of the crews on each vessel did not differ significantly.

The catch of each species for 3,000 feet of gillnet, giving each mesh size equal weight, is shown in Table 14 for three series of nightly operations. Series I represents data from operations within 100 miles of each other. Series II and III represent data from more widely located positions but still within the same statistical area.

Considering the nightly operations in the three series, the size of the salmon catch by individual vessels

TABLE 13. Salmon catches by Canadian research vessels fishing on successive nights at different stations, 1957 and 1958. Figures in parentheses are percentages.

Date	Station position	Wind force	No. of shackles fished	Catch						Percent immature	
				Sockeye	Chum	Pink	Coho	Chinook	Total	Sockeye	Chum
1957											
June 21	50°N 155°W	4	30	11 (48)	4 (18)	—	7 (30)	1 (4)	23	87	100
22		4	30	4 (25)	6 (38)	3 (19)	2 (12)	1 (6)	16	100	100
23		2	30	66 (67)	11 (11)	13 (13)	8 (8)	1 (1)	99	99	100
24		4	30	2 (50)	—	—	2 (50)	—	4	50	—
28	50°N 145°W	4	26	7 (21)	14 (43)	10 (30)	2 (6)	—	33	100	100
30		2	26	8 (8)	34 (35)	19 (20)	17 (17)	—	78	25	100
July 29	52°N 155°W	2	35	2 (40)	3 (60)	—	—	—	5	100	100
30		2	35	22 (92)	2 (8)	—	—	—	24	90	100
31		2	35	9 (36)	16 (64)	—	—	—	25	100	100
Aug. 2	52°N 145°W	2–4	35	—	11 (100)	—	—	—	11	100	—
4		5–6	35	3 (16)	14 (74)	1 (5)	1 (5)	—	19	0	100
1958											
May 17	50°N 135°W	2	40	1 (8)	—	2 (16)	9 (76)	—	12	0	—
18		2	40	5 (5)	64 (64)	10 (10)	21 (21)	—	100	0	89
19	50°N 135°W	2	40	1 (7)	8 (57)	1 (7)	4 (29)	—	14	—	71
24	50°N 145°W	4	36	41 (67)	15 (22)	4 (6)	2 (3)	1 (2)	63	72	30
25		4	36	41 (55)	26 (35)	4 (5)	4 (5)	—	75	65	12
27		2	35	78 (58)	45 (34)	11 (8)	—	—	134	74	27
June 4	58°N 145°W	2	32	113 (77)	26 (18)	7 (5)	—	—	146	2	7
5		3	32	137 (73)	19 (10)	31 (16)	2 (1)	—	189	3	0
7	55°N 150°W	3	35	101 (80)	26 (20)	—	—	—	127	1	0
8		2	35	37 (80)	8 (18)	1 (2)	—	—	46	3	0
9		2	34	34 (56)	25 (42)	1 (2)	—	—	60	3	0
10		1–2	32	155 (89)	12 (7)	5 (4)	—	—	172	0	9
23	50°N 155°W	3	22	25 (53)	13 (28)	9 (19)	—	—	47	59	58
24		2	22	61 (56)	41 (38)	3 (3)	—	3 (3)	108	62	50
25		3	22	36 (57)	14 (23)	11 (18)	—	1 (2)	62	61	64

TABLE 14. Weighted catches of salmon by Japanese research vessels fishing during the same night at closely located stations, 1956. Figures in parentheses are percentages.

Name of vessel	Date	Station position	No. of tans fished	Catch per 3,000 feet						Maximal multiple variation in catch
				Sockeye	Chum	Pink	Coho	Chinook	Total	
				SERIES I						
Eiko-maru	July 17	46°44′N 168°16′E	239	—	2 (9)	13 (59)	7 (32)	—	22	2.0
Takuyo-maru		46°18′N 168°02′E	160	—	4 (36)	5 (45)	2 (19)	—	11	
Eiko-maru	July 18	46°50′N 168°27′E	224	—	4 (8)	25 (49)	22 (43)	—	51	1.8
Takuyo-maru		46°25′N 168°07′E	160	—	7 (26)	10 (37)	10 (37)	—	27	
Eiko-maru	July 19	46°52′N 168°23′E	220	—	4 (17)	12 (50)	8 (33)	—	24	55.0
Etsuzan-maru		46°07′N 168°39′E	306	—	—	—	1 (100)	—	1	
Takuyo-maru		46°36′N 167°58′E	160	—	7 (13)	20 (36)	27 (49)	1 (2)	55	
Eiko-maru	July 20	46°50′N 168°05′E	200	—	11 (39)	9 (32)	6 (21)	2 (7)	28	2.0
Etsuzan-maru		46°48′N 167°35′E	243	—	9 (64)	2 (14)	3 (21)	—	14	
Eiko-maru	July 21	46°57′N 167°54′E	200	—	5 (39)	5 (39)	3 (22)	—	13	1.4
Etsuzan-maru		47°05′N 168°39′E	240	—	6 (43)	3 (21)	5 (36)	—	14	
Takuyo-maru		46°43′N 167°43′E	157	—	12 (63)	4 (21)	3 (16)	—	19	
				SERIES II						
Eiko-maru	July 27	56°00′N 169°47′E	150	5 (23)	17 (77)	—	—	—	22	1.7
Etsuzan-maru		57°59′N 168°33′E	149	15 (39)	23 (61)	—	—	—	38	
Eiko-maru	July 28	56°06′N 168°02′E	150	11 (15)	61 (85)	—	—	—	72	1.5
Etsuzan-maru		57°49′N 169°59′E	149	34 (32)	72 (68)	—	—	—	106	
Eiko-maru	July 29	56°14′N 166°44′E	150	42 (52)	38 (48)	—	—	—	80	1.3
Etsuzan-maru		56°08′N 169°41′E	149	25 (42)	35 (58)	—	—	—	60	
Eiko-maru	Aug. 1	56°02′N 165°00′E	150	12 (60)	8 (40)	—	—	—	20	3.0
Etsuzan-maru		56°50′N 166°20′E	150	32 (54)	28 (46)	—	—	—	60	
Eiko-maru	Aug. 2	56°10′N 167°57′E	150	14 (30)	21 (46)	11 (24)	—	—	46	1.1
Etsuzan-maru		56°11′N 167°47′E	150	26 (49)	27 (51)	—	—	—	53	

Continued

Table 14. Continued.

Name of vessel	Date	Station position	No. of tans fished	Catch per 3,000 feet						Maximal multiple variation in catch
				Sockeye	Chum	Pink	Coho	Chinook	Total	
			SERIES III							
Eiko-maru	Aug. 6	53°36′N 167°51′E	150	19 (52)	9 (25)	7 (19)	1 (3)	—	36	1.9
Etsuzan-maru		53°57′N 169°07′E	146	36 (54)	30 (45)	—	1 (1)	—	67	
Takuyo-maru		53°20′N 166°13′E	150	49 (84)	5 (9)	1 (2)	3 (5)	—	58	
Eiko-maru	Aug. 7	53°42′N 167°40′E	150	23 (55)	10 (24)	5 (12)	4 (9)	—	42	2.0
Etsuzan-maru		53°46′N 169°52′E	150	56 (68)	26 (32)	—	1 (1)	—	82	
Takuyo-maru		53°16′N 165°40′E	150	34 (79)	6 (14)	—	3 (7)	—	43	
Eiko-maru	Aug. 8	53°55′N 167°20′E	150	11 (48)	7 (30)	3 (13)	2 (9)	—	23	3.0
Etsuzan-maru		53°43′N 169°53′E	150	41 (59)	27 (49)	—	1 (1)	1 (1)	70	
Takuyo-maru		53°24′N 165°27′E	150	25 (73)	6 (18)	—	3 (9)	—	34	
Eiko-maru	Aug. 9	53°26′N 166°48′E	150	5 (28)	6 (33)	5 (28)	2 (11)	—	18	2.5
Etsuzan-maru		53°45′N 169°34′E	150	29 (63)	16 (35)	—	1 (2)	—	46	

varied by multiples ranging from 1.1 to 55.0. Excluding the highest value of 55.0, which occurred only once, the greatest difference was threefold, the average being almost twofold (1.9).

In the case of the series showing the greatest variation, judging from the species composition of the catch, the fishing date and position of the vessels, the vessel with the smallest catch (*Etsuzan-maru*) may have been operating at the extreme southern limit of salmon, even though the fishing stations of the other vessels were quite close. Therefore, the validity of this particular comparison may be suspect.

Although the rank in importance of the different species varied in the catches made on any one night, in general, usually the same species was dominant in the catches at each station. This is apparent in 10 of the 14 nightly operations. Considering the weighted nightly catch of each species at comparable fishing positions, however, the same order of importance of the various species occurred in only six of the 14 operations. Unusual, however, are the five operations from August 2 to 9. Pink salmon formed from 12% to 28% of the weighted catches made by the *Eiko-maru* but were not caught by the other vessels, even though some of the total catches were quite large.

To summarize, the size of the salmon catch on successive nights at the same station in nine series of observations usually varied threefold or less. The size of catches on the same night at closely located stations, according to 14 observations, on the average, differed twofold. This suggests that short-term variations in salmon catches are slightly greater than local variations. In spite of local or short-term variations in the catches, one and the same species usually dominated throughout a set of observations. The relative importance of the different species caught varied, however, frequently resulting in changes in the rank of a particular species.

C. Comparability of Relative Abundance Indices of Japanese Research and Commercial High Seas Fishing Vessels

As already pointed out, Japanese research vessels in each year included commercial gear in their regular complement of gillnets. In some years, exceptionally large numbers of these nets were fished (Appendix Table A). To determine whether the relative abundance indices for sockeye, chum and pink salmon computed from catch data for Japanese research vessels could be used to supplement mothership data, catch per tan values obtained from these respective opera-

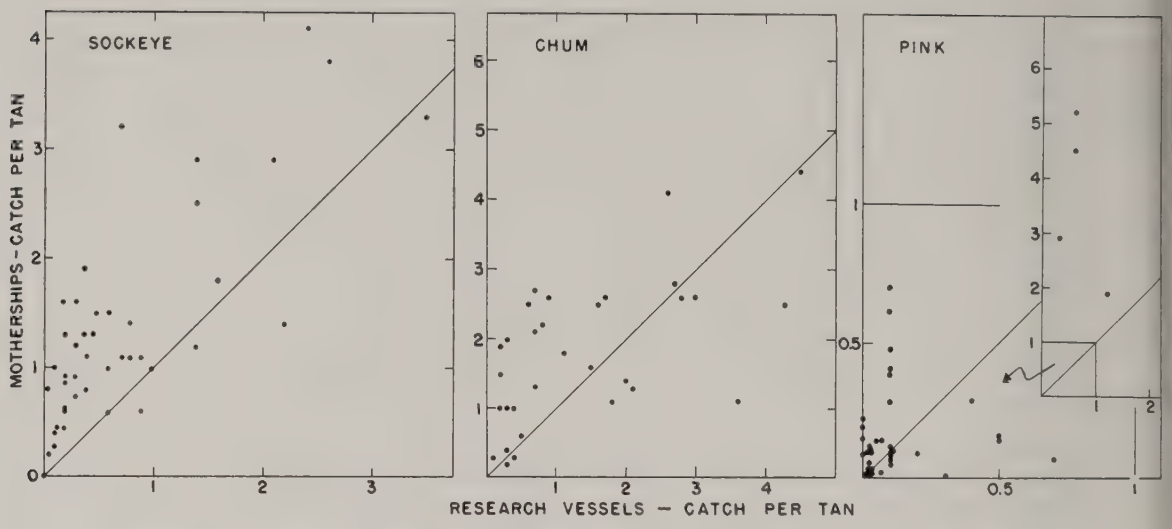

FIGURE 11. Comparison of sockeye, chum and pink salmon catch per tan values for 4.8″ gillnets fished by research and commercial vessels in the same statistical area and 10-day period.

TABLE 15. Comparison of average catch per tan values for sockeye, chum and pink salmon derived from Japanese commercial and research vessel fishing with commercial gear in the same statistical area and 10-day period.

Species	Research vessel	Mothership vessel	Ratio
Sockeye	0.78	1.54	0.51
Chum	1.39	1.78	0.79
Pink	0.27	0.65	0.41

tions within the same 10-day period and statistical area during 1955 through 1960 were plotted against each other and the positions of the various points were examined in relation to a 45-degree line representing similarity. The results of these comparisons are shown in Figure 11. The average catch per tan values for each species for this period and the ratio of research vessel to mothership indices are given in Table 15.

Of the three species, on the average, the smallest difference in the indices was recorded for chum salmon. The ratio of research to commercial vessel catches for this species is estimated as 1.39/1.78, or 0.79. Average values for sockeye and pink salmon are 0.51 and 0.41, respectively. Thus, comparing the indices for the two operations, abundance levels are lower for research vessels, and the extent of the difference varies between species.

Two possible reasons can be cited for the differences in the catch per tan values for research and commercial vessels. First, mothership vessels, through scouting vessels, are more able to locate salmon concentrations and to remain more readily in contact with these concentrations than are research vessels. Secondly, commercial vessels may fish for one species in preference to another, even though the species occur together. Commercial vessels usually set their gillnets across the presumed general migration path of the preferred species. As a result, the catch per tan indices for the preferred species may be more indicative of its relative abundance than are those indices for species of lesser importance, which may be migrating in other directions.

VI. SOCKEYE SALMON

A. Catch and Relative Abundance

1. *INPFC Research Vessel Operations*

Sockeye salmon catches made by research vessels operated by Canada, Japan and the United States since initiation of the research program in 1955 are listed by set in Appendix Table A. The weighted catch per 3,000 feet of gillnet, obtained by the method described in Section IV, is illustrated in Appendix Figure B-1 by statistical area and by 10-day period for the period 1955–1960. Table 16 shows the average weighted CPUE values by region. Changes in the relative abundance in different years are described according to the regions shown in Figure 1.

Okhotsk Sea.

Information on relative abundance of sockeye in the Okhotsk Sea from research vessel operations is

TABLE 16. Research vessel relative abundance index values for sockeye salmon, averaged by region, by 10-day period, 1955–1960.

Region	Year	May	June			July			August			Sept.
			Early	Mid	Late	Early	Mid	Late	Early	Mid	Late	
Okhotsk Sea	1959	—	—	—	—	—	1	6	—	—	—	—
	1960	—	—	—	—	—	0	12	—	—	—	—
S. E. Kamchatka—	1955	8	—	—	—	—	8	—	—	14	0	—
S. W. Aleutian	1956	3	6	30	—	27	—	45	41	6	—	—
	1957	22	15	—	16	—	20	18	24	—	—	—
	1958	1	3	—	—	—	—	56	21	17	—	—
	1959	5	—	—	—	—	6	—	—	12	—	—
	1960	10	12	4	17	—	21	102	27	10	12	—
Aleutian	1955	17	9	11	—	—	—	—	25	31	6	10
	1956	4	12	15	9	—	—	—	41	10	54	—
	1957	3	10	16	6	11	—	4	27	38	38	—
	1958	4	1	—	26	9	11	—	24	21	—	—
	1959	11	11	35	—	15	—	100	112	—	—	—
	1960	13	9	—	26	11	21	71	50	—	—	—
Western Bering Sea	1955	—	—	—	+	—	20	—	27	—	—	—
	1956	—	—	—	+	—	—	42	23	—	—	—
	1957	—	—	—	+	—	20	—	—	—	—	—
	1958	3	6	5	2	2	1	34	38	16	—	—
	1959	—	7	—	7	—	—	6	25	21	—	—
	1960	—	6	—	5	—	—	33	10	—	—	—
Central Bering Sea	1955	0	—	5	8	—	3	4	16	—	—	—
	1956	—	2	15	9	9	8	—	1	—	—	0
	1957	—	20	100	18	16	4	1	0	15	6	—
	1958	2	4	3	4	1	6	1	3	—	—	—
	1959	—	13	8	18	8	5	5	—	—	—	—
	1960	—	3	48	19	5	—	—	—	—	—	—
Eastern Bering Sea	1955	—	—	47	42	—	—	0	—	—	—	—
	1956	—	7	102	169	—	—	1	2	2	—	0
	1957	—	20	31	47	6	—	1	—	1	—	—
	1958	—	7	16	11	—	—	—	—	—	—	—
	1959	—	—	—	29	—	—	—	—	—	—	—
	1960	—	—	—	50	—	—	—	—	—	—	—
Western Gulf of Alaska	1955	—	—	—	—	—	6	10	21	—	—	5
	1956	10	—	—	—	—	13	5	27	9	—	4
	1957	—	—	—	11	—	8	7	3	—	—	
	1958	—	—	29	20	—	—	1	7	—	—	—
	1959	6	25	19	48	—	28	4	—	—	—	—
Central Gulf of Alaska	1955	—	—	—	—	—	5	—	—	2	—	1
	1956	8	8	—	—	—	6	8	6	—	—	—
	1957	—	—	15	3	17	—	—	1	0	—	—
	1958	17	11	—	—	—	—	1	—	0	0	—
	1959	12	—	—	—	—	9	5	—	—	—	—
Coastal Gulf of Alaska	1955	—	—	—	2	3	10	—	—	1	0	0
	1956	5	0	—	0	5	3	2	—	—	0	0
	1957	1	10	5	—	7	36	3	2	0	0	0
	1958	1	44	3	—	—	—	—	—	—	0	—
	1959	31	—	—	—	4	6	3	—	—	—	—

available only for July 1959 and July 1960. In 1959, catches off southwest Kamchatka indicated a low abundance level of sockeye. Along the Kuril Islands, sockeye were not caught. In 1960, in area E5048 during mid-July, medium abundance levels of sockeye were noted, and to the southwest none was caught.

Landbased Region.

Sampling by research vessels was sparse in the landbased region. Some information is available for 1955, 1956 and 1958. In May 1955 and 1956, sockeye were present in relatively high numbers in the northeast part of the region. In May 1956, they were apparently absent between Latitudes 39°N and 42°N. In May and July 1958, low abundance levels were recorded in area E5546.

Southeast Kamchatka-Southwest Aleutian.

Coverage in May and June in this region varied annually. Fishing was mainly carried out in the eastern portion of the region, except for 1958 when fishing was more extensive. In July and especially August in most years, vessels operated throughout the region, but mainly in the western portion.

A conspicuous feature was the increase in relative abundance of sockeye salmon from May through August, particularly in the western and northern parts of the region. High levels of abundance were noted in 1957 throughout the season. Very high levels of abundance were noted in late July of 1956, 1958 and 1960 (Table 16).

South of the Aleutian Islands.

Sampling in this region was relatively extensive in most years, except during July in 1955 and 1956. In May and early June, sockeye salmon were present over a wide area as far south as Latitude 45°N (1956 and 1960), but no further (1956). Abundance levels tended to be higher close to the Aleutians than further offshore. In 1960, however, good numbers were taken offshore to the south. Following mid-June, abundance levels increased rapidly and were highest in late July and August, reaching especially high levels in 1959 and 1960 (Table 16). In late August, the southern limit of the catches was about Latitude 49°N.

Western Bering Sea.

Sampling in June and early July (1958 and 1960) indicated that sockeye salmon abundance levels were low. Levels later in July and August, in most years, were considerably higher, reaching high levels in 1956, 1958 and 1960 (Table 16), thus resembling events observed in the Southeast Kamchatka-Southwest Aleutian region.

Central Bering Sea.

Sampling was conducted in this region during various months each year, but was especially extensive during June. Fishing in 1958 in the southern portion showed that sockeye salmon were present at least by late May. They were most abundant during the middle and late periods of June in the eastern part of the region, reaching very high abundance levels in mid-June 1957 and in late June 1960 (Table 16). In July, abundance levels declined. Low levels continued through August.

Eastern Bering Sea.

Sockeye salmon were extremely abundant in this region during the latter part of June in all years except 1958. Very high abundance levels were recorded in 1955, 1956, 1957 and 1960. Scattered sampling later in the season (1956 and 1957) showed that sockeye salmon were present in low abundance or were absent.

Western Gulf of Alaska.

Information on distribution and relative abundance in this region is based on scattered sampling. A set made in early April 1959, near Kodiak Island, caught one sockeye. Also in 1959, relative abundance levels increased through May and June south of Kodiak Island. Abundance levels were very high in 1957 and 1959 south of the Alaska Peninsula. August catches showed a wide range in abundance levels annually and no consistent trend between areas. The southern limit of sockeye salmon appeared to be about Latitude 49°N in August. The distribution and trend in relative abundance south of the Alaska Peninsula was similar to the pattern described for waters south of the Aleutians.

Central Gulf of Alaska.

Fishing, except in 1956, was more scattered in this region than in most other regions of the North Pacific and Bering Sea. The catches indicated that abundance levels were usually low in each month of each year's fishing. In 1956, particularly in July, abundance (although generally low) tended to increase westward (Appendix Table C). The area in the southeast portion of the region where sockeye were absent enlarged through the fishing season.

Coastal Gulf of Alaska.

This region includes the coastal areas through which maturing sockeye move to the spawning areas along the Pacific coast of North America from Cook Inlet, Alaska, to the Columbia River. Catches in May 1959 and early June 1958 showed very high abundance

levels in the northern part. A high level was recorded from southwest of the Queen Charlotte Islands in mid-July 1957. After mid-July, sockeye salmon were present at low levels and none was caught later than mid-August.

2. *Mothership Operations*

(a) Catch.

In spite of the influence of fishing effort upon catch, areas producing large catches of sockeye salmon indicate to some extent areas of abundance. Changes in location of these more productive areas with time are therefore indicative, in general, of movement and distribution of the bulk of the sockeye available. This is especially true for widespread, large-scale operations such as the mothership fishery.

The reported annual sockeye catches by mothership operations from 1952 to 1960 in the North Pacific, Okhotsk Sea and Bering Sea are given by month in Table 17. Appendix Figure C-1 illustrates these data in greater detail, showing the catch by 10-day period and by statistical area as well as the cumulative catch for 5-degree intervals of longitude. This figure is based on detailed data given in Appendix Table D, which also lists fishing effort in thousands of tans of gillnet. The catches are treated by major regions.

North Pacific. The North Pacific is the principal mothership region, where 68.7 million sockeye (85% of total sockeye landings) were caught during the period 1952–1960 (Table 17). From 1952 to 1955, the developing fishery was marked by increases in gear (Table 3), expansion of fishing areas and improvements in equipment and techniques. Sockeye salmon landings during these years increased from 0.7 million to 10.4 million salmon (Table 17). In 1956, the sockeye salmon catch in the North Pacific dropped to 7.6 million, the decline in part being due to restrictions arising from Japan-Soviet treaty negotiations. The fishery expanded eastward to Longitude 175°W and northward into the Bering Sea in 1956. Catches in 1957 in the North Pacific amounted to a record high of 14.9 million fish. Annual catches thereafter fluctuated considerably, amounting to 12.0 million in 1958, 7.9 million in 1959 and 9.8 million in 1960.

The fishing season in the North Pacific in the years 1952–1960 began at different times in May and ended in late July or August (Table 2). The start of the season in 1959 and 1960 was delayed until late May, due to extended Japan-Soviet fishery negotiations. As a result, a larger part of the catch than usual was made in June and July.

Catches in May in most years, especially after 1954, were made mainly between Longitudes 165°E and 175°E. In 1956, however, large catches were made as far east as Longitude 180°, when fishing was restricted west of the Russian Edict (Bulganin) Line (Longitude 170°E) until mid-July. Catches in June in most years were principally from waters between Longitudes 160°E and 175°E, slightly west of the sockeye concentrations in May. In 1956, however, the areas of good catches were farther to the east between Longitudes 170°E and 175°W. In July, the largest catches were made between Longitudes 160°E and 170°E. Exceptions to this tendency were the years 1956 and 1960 when good catches were made as far east as Longitudes 175°W and 175°E, respectively, and 1958 when good catches were made as far west as Longitude 155°E. In some years, quotas were filled in July. In years when the season extended into August, best catches usually were made between Longitudes 160°E and 165°E; in 1954, however, highest catches were made farther west between Longitudes 155°E and 160°E and, in 1960, farther east between Longitudes 170°E and 175°E.

Table 17. Sockeye salmon catches (in thousands of fish) by Japanese mothership operations, 1952–1960.

	North Pacific					Bering Sea				Okhotsk Sea				
Year	May	June	July	Aug.	Total	June	July	Aug.	Total	June	July	Aug.	Total	Total
1952	165	329	243	1	738	—	—	—	—	—	—	—	—	738
1953	268	445	823	31	1,567	—	—	—	—	—	—	—	—	1,567
1954	445	1,028	1,909	424	3,806	—	—	—	—	—	—	—	—	3,806
1955	2,416	3,941	2,620	1,426	10,403	—	—	—	—	33	124	143	300	10,703
1956	1,825	2,319	2,247	1,198	7,589	1,161	494	—	1,655	27	566	64	657	9,901
1957	5,888	5,592	3,398	—	14,878	4,732	217	—	4,949	32	243	—	275	20,102
1958	2,539	5,063	3,414	953	11,969	—	—	—	—	12	33	9	54	12,023
1959	2,152	3,973	1,772	—	7,897	45	1,183	—	1,228	—	—	—	—	9,125
1960	1,133	2,196	6,143	359	9,831	2,891	157	—	3,048	—	—	—	—	12,879

The areas of good catches also changed latitudinally in position from May to August, indicating a northward component in the general distribution pattern of the species as it moved westward. In most years during 1955 though 1960, the southern and northern latitudes delimiting the areas of relatively good catches were respectively 48°N and 50°–52°N in May; 48°N and 52°N in June; 50°N and 52°N in July.

Thus, according to sockeye salmon catches in the North Pacific by motherships, the area of sockeye abundance in May is located in most years between Longitudes 165°E and 175°E and Latitudes 48°N and 50°N–52°N. As the season advances the areas of abundance shift northwestward.

Bering Sea. Fishing in the Bering Sea was first carried out in 1956. According to the tri-partite North Pacific Convention agreement, fishing is limited to waters west of Longitude 175°W. The combined catch of sockeye salmon in the years 1956 to 1960 amounted to 10.9 million fish, or 13.4% of the total (1952–1960) mothership landings of sockeye (Table 17). In 1956, the catch amounted to 1.7 million, or 16.7% of the total sockeye salmon catch in that year. The peak year was 1957 when 4.9 million sockeye were caught, comprising 24.6% of the total sockeye salmon catch. Low abundance of sockeye discouraged operations in the Bering Sea in 1958. Landings in 1959 included 1.2 million sockeye, or 13.5% of the total sockeye salmon catch during a predominantly pink salmon year. In 1960, 3.0 million sockeye were caught, comprising 23.7% of the total sockeye salmon catch.

Large catches of sockeye were made in the mid-June and late June periods, especially in 1957, but also in 1960 and 1956, mainly between Longitudes 175°E and 175°W. The most productive areas were 8052, 8054 and E7552. The latter area produced the largest catch of sockeye reported from any single area, 1.6 million during the mid-June period in 1957 (Appendix Table D). In 1959, best catches were made throughout July between Longitudes 170°E and 175°E north of Latitude 56°N.

Okhotsk Sea. Fishing in the Okhotsk Sea was limited to the four-year period 1955–1958, cessation being the result of Japan-Soviet fishery agreement. The catches totalled 1.3 million sockeye, or about 1.6% of the total (1952–1960) mothership catch of the species (Table 17). The annual catch increased from 0.3 million in 1955 to almost 0.7 million in 1956, and then declined during the succeeding two years. The months of best catch differed annually, but tended to be earlier in later years. Catches were mainly made in statistical areas E5050 and E5052.

(b) Relative Abundance.

Appendix Figure D-1, based on data in Appendix Table D, shows the sockeye salmon catch per tan (180 feet) values by statistical area by 10-day period for 1952 though 1960, for mothership operations. Supplemental data from research vessels using large quantities of commercial gillnet are also shown. As reported in Section III, changes in construction of commercial gillnets occurred in the early years of the fishery, but the nets were reasonably standard at 4.8" nylon mesh from 1955 to 1960. The relative abundance data for the mothership fishery are described below according to major fishing regions, using categories of low, medium, high and very high as given in Section IV.

North Pacific. Annual sockeye catch per tan values in the North Pacific ranged from a low of 1.1 in 1956 (a year of restricted fishing) to a high of 2.9 in 1957 (Table 18). The second highest value was 2.2 in 1960. In other years, values ranged from 1.2 to 1.6. Changes within and between years in relative abundance are described below, using Appendix Figure D-1 as the main guide.

In 1952, the first year of post-war mothership operations, high abundance levels were reached in area E7550 south of the western Aleutian Islands in late May and early June. Later in June and into July, medium levels were noted in areas to the west. In late July and early August, abundance levels were low.

Expanding mothership operations in 1953 covered a wider area than in 1952. Highest abundance levels were recorded from late June through mid-July in areas off southeast Kamchatka, levels ranging from medium to high. By early August, levels were low.

TABLE 18. Annual sockeye salmon catch per tan values in mothership operations by major fishing region.

Year	North Pacific	Bering Sea	Okhotsk Sea
1952	1.6	—	—
1953	1.2	—	—
1954	1.2	—	
1955	1.5	—	0.4
1956	1.1	0.8	1.4
1957	2.9	3.5	0.5
1958	1.4	—	0.1
1959	1.4	0.8	—
1960	2.2	1.6	—

In May 1954, the fishery was concentrated in eastern areas south and southeast of Attu Island. High levels of abundance were noted in mid-May in areas E7048, E7550 and E7548. In June, south of Attu Island, low levels were recorded, with medium levels to the westward. In early July, high levels were noted southwest of Attu Island in areas E6548 and E6550. In middle and late July, in areas E6050 and E6052 off southeast Kamchatka, high levels were present. In August, highest levels (low to medium values) were recorded off the southeast tip of Kamchatka.

In May 1955, between Longitudes 165°E and 180° and north of Latitude 48°N, abundance levels were medium in most areas fished, high in area E7048. In June, medium to high levels were recorded in a number of adjacent areas, with abundance levels still high in late June in area E7048. In early July, in the Southeast Kamchatka-Southwest Aleutian region, highest abundance levels were present in areas E6050 and E6550. Thereafter, abundance levels declined but were higher in the northern than in the southern areas fished. Supplementary information in 1955 from research vessels using commercial gear indicated medium levels south of the Aleutians in late May at area E7548 and high levels at area W7052 in mid-June. Abundance levels decreased south of area W7052.

In 1956, the mothership fleets were spread farther to the east and north than in previous years, since fishing west of Longitude 170°E was prohibited until mid-July. East of Longitude 170°E in May, sockeye were present in low to medium abundance. Abundance levels increased through June and were generally higher close to the Aleutians. In July, sockeye abundance levels were highest off southeast Kamchatka, reaching a very high, maximal level in area E6052 in late July. Early August levels in most areas were lower than in July. A high level was noted in area E6552 west of Attu Island in early August. Supplementary data from research vessels with commercial gear, fishing in southern latitudes in late May, showed small catches of sockeye salmon as far south as Latitude 44°N and none below Latitude 44°N.

In 1957, high to very high abundance levels were recorded during May over a broad expanse of the North Pacific, between Longitudes 155°E and 175°E, and between Latitudes 46°N and 54°N. In June, the catch per tan values were high to very high in all areas fished from Longitude 160°E eastward to Longitude 180° and from Latitude 46°N northward to Latitude 54°N. Mid-June abundance levels were very high in most of these areas. In July, fishing was conducted mainly between Longitudes 160°E and 170°E, Latitudes 48°N and 54°N, and also to the west in area E5550. Abundance levels were high in the northern areas, west of Attu Island and off Kamchatka, and decreased to the southwest. Abundance levels off southeast Kamchatka declined through July.

In 1958, abundance levels were much lower than in 1957. In May and June, highest levels were recorded between Longitudes 165°E and 170°E, ranging from medium to high and centering at area E6548. Levels during this period fluctuated, with maximal levels occurring in mid-May and late June. In early July, sockeye abundance levels were very high and highest directly west of the Aleutians. In mid and late July, as the fleets moved westward, abundance levels were mostly low to medium. In early August, abundance levels were high in area E5550 adjacent to the southern tip of Kamchatka, medium to the east and low to the south.

In 1959, in late May, sockeye were present in medium to high levels of abundance between Longitudes 165°E and 170°E. In the central part of the North Pacific fishing grounds in June, abundance levels dropped. In July, abundance levels increased considerably. A very high, maximal abundance level occurred in mid-July in area E6550.

In 1960, in late May, the areas of maximal abundance in the North Pacific were areas E6550, E6548 and E7048, where high abundance levels were noted. Highest abundance levels in June were reached during mid-June directly south of the western Aleutians, where very high levels were recorded. In June, abundance levels decreased to the westward. In July, abundance levels increased to the west and south, reaching a very high, maximal level in area E6548. In August, fishing took place only west of Longitude 175°E, and very high levels were recorded west and south of the western Aleutians in areas E6552 and E7550.

Bering Sea. As pointed out previously, the mothership fleets fished in the Bering Sea in 1956, 1957, 1959 and 1960. Annual catch per tan values ranged from 0.8 in 1956 and 1959 to 3.5 in 1957 (Table 18).

In 1956, fishing took place from mid-June through early July north of the Aleutians between Longitudes 170°E and 175°W. Abundance levels were low to medium in late June, decreasing slightly in early July. In late July, a very high abundance level was noted in the extreme western Bering Sea. In August in area E7052, adjoining Attu Island, the relative abundance level was very high.

In 1957, fishing again took place in the Bering Sea from mid-June through early July. Fishing indicated very high abundance levels in mid-June in areas E7554, E7552, 8052, 8054 and 8056. A large concentration of sockeye was present in this region. Although abundance levels declined during the last 10 days of June, very high levels were still recorded in the easterly areas. In early July, after the fleets had left these areas, low to medium abundance levels were noted to the north. In mid-July, medium catches were made in areas E6556 and E6558. The outstanding feature for 1957 was the very high abundance level of sockeye in the central Bering Sea in mid-June.

In 1959, fishing in the Bering Sea began in June in the vicinity of Attu Island. Medium abundance levels were noted in mid-June and late June. In July, the fishery expanded to the western and north central regions. Relative abundance levels were low to medium in July.

In 1960, motherships operated north of the Aleutians as far east as Longitude 175°W during mid-June and late June. A maximal, very high level of abundance was recorded in mid-June in area 8052, directly north of the Aleutians. Catches declined progressively northward, with high levels being noted for area 8054 and medium levels for area 8056. In late June, abundance levels decreased, although levels were still high in the southern areas. Relatively low numbers of sockeye were taken as far north as areas E7560 and 8060 and as far west as areas E6556 and E6558 in late June. In July, the latter two areas showed some increase in relative abundance. Supplementary catches by research vessels using commercial gear tend to corroborate the distribution pattern apparent from mothership operations.

Okhotsk Sea. Sockeye were less abundant in the Okhotsk Sea than in the two other major regions in the years 1955 to 1958. Annual catch per tan values ranged from 0.1 in 1958 to a maximum of 1.4 in 1956 (Table 18). Relative abundance levels were low in June (Appendix Figure D-1), increased through July, and reached peak levels in late July (early August in 1955).

3. *Landbased Region Operations*

Information on the seasonal distribution and relative abundance of sockeye salmon in the landbased fishery region is available from research vessels and training vessels fishing with commercial gear authorized for that region (4.5″ mesh). These vessels operated mainly during May and June in the years 1956–1960. Sockeye represent a minor part of their catch. Values representing relative abundance levels of sockeye are shown by small circles in Appendix Figure D-1.

Considering relative abundance data for the landbased region for all years collectively, it would appear that sockeye in May were absent or very scarce near the Kurils and increased in numbers offshore. Data for 1956, 1958 and 1960 indicate that sockeye were most abundant in the northeast sector of the region (areas E6046 and E6044). In 1958, fishing was conducted in May south of Latitude 40°N, but sockeye were not caught south of Latitude 42°N. Thus, Latitude 42°N would appear to be the southern limit in May. In June, relative abundance indices were very low in waters off the Kurils, but were medium further offshore in area E6046.

4. *Summary*

Surface gillnet catches by the Japanese mothership fishery, Japanese training vessels and research vessels of Japan, Canada and the United States engaged in the INPFC program were used to determine the ocean distribution and monthly changes in the relative abundance of sockeye salmon. In each year from May through August, a basic distribution pattern was evident, even though coverage of the total ocean area occupied by sockeye salmon varied annually in time and space. This basic distribution pattern for the North Pacific and Bering Sea is schematically depicted in Figure 12. This figure was prepared by ranking the 10-day CPUE indices for each source of data (i.e., mothership, research and training vessels) and statistical area since 1955, obtaining a mean monthly rank index for each statistical area and classifying this mean index according to one of four broad categories (absent, low, medium, high to very high) representing relative abundance.

In May, sockeye were widely distributed in the offshore waters of the North Pacific. The southern limit appeared to be between Latitudes 42°N and 45°N in the western Pacific and between Latitudes 47°N and 49°N in the eastern Pacific. In almost all sampling areas north of these limits, sockeye were present in May. Limited sampling in the southern Bering Sea in May also showed sockeye to be present. Data are lacking for areas further north in the Bering Sea and for the Okhotsk Sea. The southern limit of sockeye salmon in May is shown schematically in Figure 12.

Largest catches in May by the mothership fishery were recorded southwest of the western Aleutians between Longitudes 165°E and 180° and Latitudes 46°N and 54°N. Catches were high in 1957 and low in 1956. (Fishing was prohibited west of Longitude 170°E in 1956 until mid-July.)

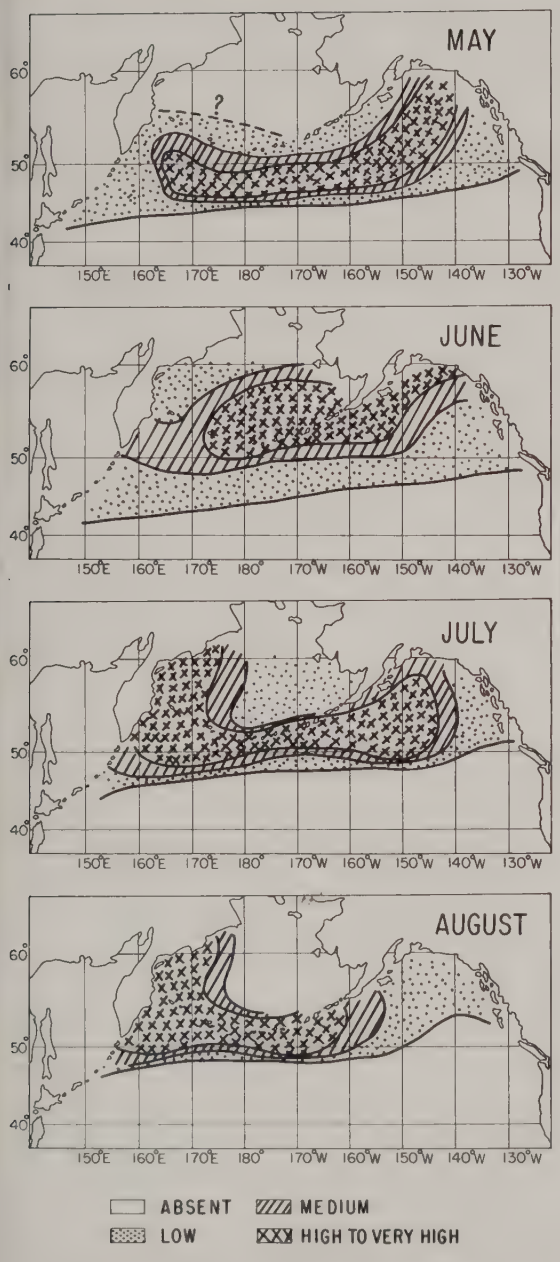

FIGURE 12. Schematic diagram showing distribution and relative abundance of sockeye salmon, May through August, maturing and immature fish combined.

CPUE values in May from mothership operations showed highest abundance levels south and southwest of the western Aleutians, extending west toward Kamchatka and north to include the area adjoining Attu Island. High levels were noted in 1957 westward to at least Longitude 160°E.

Research vessel CPUE values were high in May 1957, southwest of the Aleutians, agreeing relatively with values from the motherships. In other years, from scattered samples, CPUE values from research vessels indicated lower levels than those based on mothership operations. In the eastern Pacific in May, abundance levels from scattered sampling by research vessels were low to medium, except in 1959 when a high level was recorded in the far north.

In June, large catches, fluctuating annually, were made by the mothership fleets in the Southeast Kamchatka-Southwest Aleutian region. In some years, areas in which sockeye were abundant extended eastward to the central Aleutian Islands. Very high catches were made in 1957 and 1958, followed in rank by 1955, 1959, 1956 and 1960. In the Bering Sea, mainly between Longitudes 175°E and 175°W, very high catches were made in 1957 and 1960, lesser catches in 1956. In the Okhotsk Sea, sockeye catches in June were relatively small.

CPUE values in June from the mothership operations southwest of the Aleutians approximated May values in most years, except in 1959 when values dropped and in 1956 when values increased. Sockeye in June were moderately abundant, particularly in 1957. In that year in the Bering Sea the mothership CPUE values were very high in June. Also in June 1960, the Bering Sea yielded high CPUE values, although much lower than in 1957. Okhotsk Sea catches in June (1955 to 1958) showed very low abundance levels.

Abundance levels obtained from research vessel catches in June of most years in the Southeast Kamchatka-Southwest Aleutian region resembled those of May. To the east in the Aleutian region, CPUE values in most years were much greater than in May, with highest June values in 1960. In the central Bering Sea, June values were high in 1960 and very high in 1957. In the eastern Bering Sea, June values were medium in 1958, high in 1955 and 1959, and very high in 1956, 1957 and 1960. In the Gulf of Alaska in June, high levels of abundance were recorded by research vessels in 1958 and very high levels in 1959, south of Kodiak Island. In the northern Gulf of Alaska in June 1958, a high abundance level was noted. Other June catches in the Gulf of Alaska indicated low to medium abundance levels.

In July, catches by the mothership fleets in the Southeast Kamchatka-Southwest Aleutian region in most years were lower than in June, but 1960 was a

noteworthy exception when catches nearly tripled from June to July. Catches in the Bering Sea dropped off sharply from June to July in most years, and here the noteworthy exception was 1959 when highest catches were taken in July (west of Longitude 175°E). Okhotsk Sea catches increased greatly in July (especially in 1956 when fishing was prohibited off eastern Kamchatka and the Kurils), but the Okhotsk Sea catches were low in all years compared with other fishing regions.

CPUE values from the mothership operations in July in the Southeast Kamchatka-Southwest Aleutian region decreased from June in 1957 and 1958 and increased in 1959 and especially 1960. South of the Aleutians, CPUE values decreased from June to July in all years, although 1955 remained fairly stable. Sharp drops in CPUE values were noted in 1957 and 1960 in July in the central Bering Sea. In the western Bering Sea, high CPUE values were obtained in late July 1956 and medium CPUE values in mid-July 1956. In the Okhotsk Sea, CPUE values increased from June to July, reaching highest levels in 1956.

Research vessel CPUE values in July increased over June in the Southeast Kamchatka-Southwest Aleutian region, reaching high levels in 1956, 1958 and 1960. In the Aleutian region, high levels were maintained in July, and in 1959, CPUE values increased sharply to very high levels. The Western Bering Sea region showed high July levels in 1956, 1957 and 1960. The Central Bering Sea region showed low levels in July of all years. Samples from three years in the eastern Bering Sea showed low levels in July. In the western Gulf of Alaska, very high levels were recorded in July 1959, south of the Alaska Peninsula. The Central and Coastal Gulf of Alaska regions yielded mainly low CPUE values (a notable exception was in mid-July 1957, south of the Queen Charlotte Islands).

In August, the catches by the mothership fishery decreased considerably from July (in 1957 and 1959 quotas were filled during July) because of varying termination dates in fishing. Largest August catches were made in 1955 and 1956 off southeast Kamchatka and southwest of the Aleutians. No fishing took place in the Bering Sea in August. Okhotsk Sea catches were low.

High CPUE values were obtained in the mothership operations in early August 1960 from the Southeast Kamchatka-Southwest Aleutian region, including the area adjoining Attu Island. This area, as well as adjacent areas to the west, yielded high CPUE values also in early August 1956.

Research vessel CPUE values in August in the Southeast Kamchatka-Southwest Aleutian region showed medium to high levels of abundance in all years. In the Aleutian region, very high August levels were noted in 1959 and 1960. In the western Bering Sea, medium to high levels were recorded in all years sampled. In the eastern Bering Sea, from sparse sampling, very low levels were indicated in August. In the western Gulf of Alaska, high CPUE values were obtained in 1955 south of Unimak Pass. In 1956, medium values south of Kodiak Island and the Alaska Peninsula were recorded. In 1957 and 1958, August CPUE values in the western Gulf of Alaska were low, while in 1959 and 1960 sampling was negligible. In the Central and Coastal Gulf of Alaska regions, average CPUE values were low in August in years sampled.

The southern limit of sockeye salmon distribution was pointed out previously for the month of May. By August, the southern limit (Figure 12) had shifted northward to Latitude 48°N in the western and central Pacific. In the eastern Pacific, sockeye salmon appeared to be absent in a large expanse of the southeast portion of the Gulf of Alaska (roughly Latitude 52°N).

B. Distribution of Immature and Maturing Sockeye Salmon

1. *INPFC Research Vessel Operations*

The percentages of immature sockeye salmon in the research vessel catches by statistical areas and 10-day periods during 1956 through 1960 are shown in Appendix Figure B-1 by numerical values directly above the circles representing relative abundance levels. Each value was determined from a sample of at least 10 fish, and most samples were considerably larger. The method used for establishing maturity was explained in Section IV.

Maturity data are lacking for 1955. Those for 1956 are limited mainly to the Gulf of Alaska. The 1957, 1959 and 1960 maturity data are complete for most research vessel samples. Data for 1958 are for samples from the central and eastern regions, and are lacking for most samples from the western regions. The distribution of sockeye salmon according to maturity is described below according to region.

Okhotsk Sea.

Research vessel samples are available only for July 1959 and July 1960. A few immatures were taken; maturing fish predominated.

Landbased Region.

Maturity data obtained from sampling catches are

lacking. Since each of the 16 sockeye caught in mid-July 1958 in area E5546 was taken in small-meshed gillnets, the bulk of the sockeye present is presumed to be immature. The date and location of the catches would support this view.

Southeast Kamchatka-Southwest Aleutian.

In May, immature sockeye were rarely caught, the highest percentage of immatures in any sample being 9%. Generally, June samples also contained few or no immatures, but exceptions did occur; immatures were estimated to form 50% of a mid-June sample in 1958 and 77% of a late June sample in 1960. In July, the percentage of immatures continued to increase, ranging from 40% to 94% of the sockeye salmon caught. By August, immatures were largely dominant (85% to 100%).

South of the Aleutian Islands.

In this region, in May and June, the estimated proportion of immatures in the samples varied greatly. In 1958 and 1959, in May, most sockeye salmon were maturing, but in 1957 and 1960 most were immature (1960 samples were from south of Latitude 48°N). The proportion of immatures in June samples was highly variable, ranging from 1% to 100%. Samples in June taken farther offshore to the south in general contained a higher proportion of immatures than those taken close to the Aleutians. Also, close to the islands, immatures generally increased in importance through June. Further increases in importance of immatures were noted for July (50%–100%) and by August they formed virtually the whole sockeye population (92%–100%).

Western Bering Sea.

In May, in the Western Bering Sea region, scattered sampling showed immatures to be very scarce. In June, a few were taken (usually 0% to 15%). Through July, there was a distinct change-over from maturing to immature individuals, estimates of the proportion of the latter in samples ranged from 73% to 100%. In August, practically all the fish were immature, ranging from 95% to 100% (1959 and 1960).

Central Bering Sea.

In May, from a few samples taken in 1958 and 1960 close to the Aleutians, the estimated percentages of immatures ranged from 0% to 63%. In June, the fish were predominantly maturing. Many samples taken in mid-June during the period of peak abundance contained no immatures. Late June samples also consisted mainly of maturing fish. However, late June samples in 1959 north of Latitude 58°N contained immature and maturing fish in about equal numbers. In July, especially mid-July and late July, the maturing fish were replaced almost entirely by immatures. In August (1957 and 1958), the percentages of immatures in the samples ranged from 90% to 100%.

Eastern Bering Sea.

No samples were collected in May, but in June practically all the fish were maturing. Sparse sampling in July indicated that most fish were maturing. However, one small sample in early July 1957, in the western part, consisted entirely of immatures. In August (1957 and 1958), the few samples collected were taken near the Aleutians and the Alaska Peninsula. In 1957, the fish were mainly maturing; in 1958, mainly immature.

Western Gulf of Alaska.

The only sampling in May (and late April) was in 1959 near Kodiak Island and all the fish were maturing. In June, sockeye salmon in the northern areas were mainly maturing, while in the southern areas they were mainly immature. In July, the samples consisted predominantly of immature fish. One sample in 1957 south of Kodiak Island contained maturing and immature fish in about equal numbers. In August, the fish were largely immature.

Central Gulf of Alaska.

May and June samples south of about Latitude 50°N included mainly immature fish, while in the northern part of the region in June the fish were mainly maturing. In July, maturing fish predominated in the eastern areas and immatures predominated in the central and southern parts of the Gulf of Alaska (based mainly on 1956 samples). Small samples in August 1957 consisted of both maturing and immature sockeye. One sample in September 1957, from area W5054, was 100% immature.

Eastern Gulf of Alaska.

Scattered sampling along the North American coast showed that the fish were predominantly maturing throughout the season. Exceptions included one small sample in May 1958, off the northern tip of Vancouver Island, which contained 60% immature fish; another in August 1957, in the northern part of the region, consisted entirely of immatures.

2. *Mothership Operations*

Figure 13 shows the percentage of immature individuals in sockeye salmon samples from the mothership catches. The hatched areas show the main fishing areas and presumably the samples are mainly representative of these general areas. The exact numbers

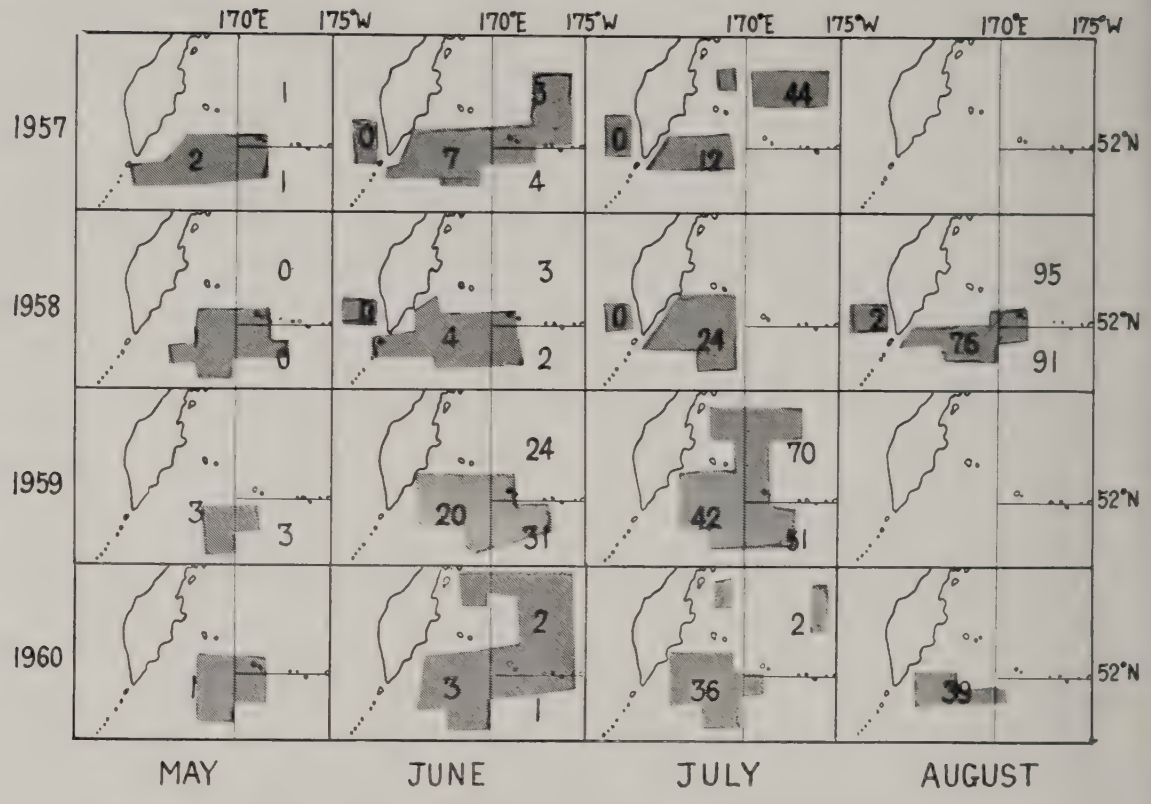

FIGURE 13. Percentage of immature individuals in sockeye salmon samples from the mothership fishery, 1957–1960. Shaded areas indicate fishing areas.

of fish comprising the samples are unknown, but they are regarded to be large. The data are presented by month for the years 1957 to 1960 according to four large mothership regions: Okhotsk Sea; North Pacific and Bering Sea west of Longitude 170°E; Bering Sea east of Longitude 170°E; and North Pacific east of Longitude 170°E.

Commercial gillnets used in the mothership fishery do not catch immature, 1-winter-ocean sockeye salmon, except in negligible numbers, because of the small size of the fish. Immature sockeye taken in mothership operations are predominantly 2-winter-ocean fish.

Considering first the samples from the Okhotsk Sea, in June and July, the sockeye salmon were entirely maturing fish. In August 1958, only 2% were immature fish.

In the North Pacific and Bering Sea in May, almost all sockeye salmon were maturing fish. The percentage of immatures ranged from 0% to 3% in all regions and in all years sampled.

In June, the percentages of immatures increased over May levels. The increase was very slight in 1957, 1958 and 1960, with percentage values ranging from 1% to 7%. In 1959, however, immature sockeye salmon formed from 20% to 31% of the samples in the three regions, with the highest value occurring south of the Aleutian Islands.

In July, the percentages of immature sockeye increased sharply over June levels, except in 1960 in the central Bering Sea. Highest percentages of immatures were taken in 1959, with percentage values ranging from 42% in samples from west of Longitude 170°E and 70% in samples from the Bering Sea.

In August, in the two years sampled, the percentages of immature sockeye were higher than in July. In 1958, very high percentages of immatures were taken, ranging from 76% to 95% in the three regions. In 1960, in the region west of Longitude 170°E (only region sampled), the percentage of immatures was 39%. Sockeye catches in the mothership fishery in August were small compared to catches in previous months.

Summary

Sockeye salmon in May were mainly maturing fish throughout all regions fished by mothership and research vessel operations. Exceptions occurred in the research vessel catches in the central Aleutian Islands (especially offshore to the south) and in the southern Gulf of Alaska (south of about Latitude 50°N), where small samples mainly consisted of immatures.

In June, most of the sockeye in most regions were maturing fish. Mothership operations yielded low percentages of immatures (1% to 7%), except in 1959 when the percentages of immatures by region were higher (20% to 31%). Exceptions in the research vessel catches occurred south of the Aleutians and in the southern Gulf of Alaska, where immatures predominated. The small-meshed gillnets used by research vessels take a higher percentage of small, immature sockeye than do the commercial gillnets in the mothership fishery.

In July, research vessel samples showed that a distinct change-over from maturing to immature fish took place in most regions. Maturing fish were limited mainly to coastal areas, namely off southwest Kamchatka in the Okhotsk Sea, off southeast Kamchatka, off Bristol Bay and off the North American coastline from Cook Inlet south to Vancouver Island. In the mothership operations, the percentage of immatures increased considerably from June to July, but maturing fish still formed a greater part of the catch than immatures in most regions in most years. Highest percentages of immatures occurred in the 1959 samples, 70% in the Bering Sea east of Longitude 170°E and 51% south of the Aleutians east of Longitude 170°E.

In August, research vessel samples, with few minor exceptions, consisted almost entirely of immature fish. Motherships did not operate in August of 1957 and 1959. In 1958, mothership samples consisted of maturing fish in the Okhotsk Sea but mainly immature fish in the North Pacific. In 1960, off southeast Kamchatka, the samples consisted of 61% maturing fish and 39% immatures. The numbers of sockeye taken in the mothership fishery in August were small compared to catches in previous months.

The general monthly distribution pattern of immature and maturing sockeye salmon, considering the results of analyses of data from research and commercial operations, is schematically shown in Figure 14.

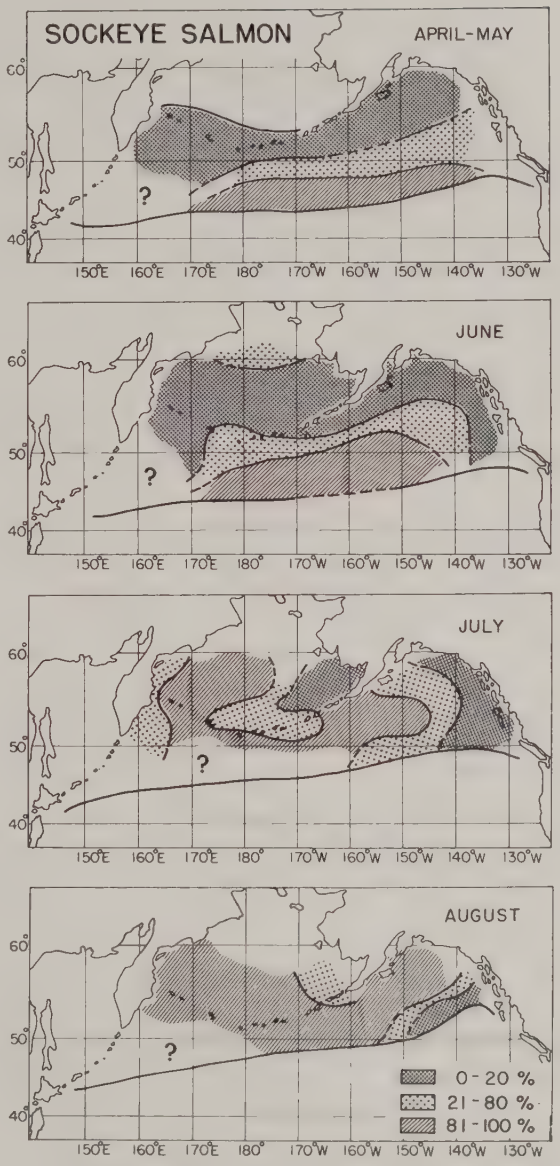

FIGURE 14. Schematic diagram showing the distribution of immature sockeye salmon in the North Pacific and Bering Sea, by month.

C. Distribution of Sockeye Salmon by Age

1. *INPFC Research Vessel Operations*

(a) Ocean Age.

The ocean age composition of sockeye salmon caught by INPFC research vessels is given by statistical area for each month for the years 1956 to 1960 in Table 19. "Ocean age" refers to the number of winters a fish

TABLE 19. Ocean ages (weighted) of sockeye salmon caught

Month	Lat. (°N)	Year	Longitude																													
			150°E				155°E				160°E				165°E				170°E				175°E				180°				175°W			
			1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
May	58	1959																																
	54	1956																																
		1958																	–	1	1	1												
		1959																																
	52	1956																																
		1957													–	–	16	1													–	2	1	–
		1958																						2	–		–	–	1	1				
		1959																																
		1960																	+	2	8	+												
	50	1956																																
		1957													-	2	19	–																
		1958																									+	2	2	–				
		1959																	1	4	–	–	+	5	3	+	1	7	4	–	–	8	2	–
		1960																	–	2	6	1					–	4	7	–	–	18	6	+
	48	1956																																
		1957													–	5	12	–	–	2	25	–										2	1	–
		1958																										2	1	–				
		1959																	–	2	1	–	–	4	1	–								
		1960																														9	5	–
	46	1956																																
		1960																									–	1	1	–	–	3	1	–
	44	1960																													2	18	2	–
June	60	1959																									–	5	1	–				
	58	1958																																
		1959																									4	5	1					
	56	1956																																
		1957																														9	31	
		1958																																
		1959																	–	9	5	–	2	5	4	–	1	15	4	–	1	16	4	–
		1960													1	1	3	–	3	1	6	–	–	3	2	–					3	24	9	–
	54	1957																									–	14	44	–				
		1958																	–	1	5	1	1	2	2	–	–	1	2	–	+	3	2	–
		1959																	–	5	8	+					+	7	4	–				
		1960													+	2	6	–	+	1	2	–	1	4	5	–	1	17	3	–	4	54	2	–
	52	1957																	–	1	3	–	4	4	8	–	–	15	23	–	–	10	10	–
		1958																	–	1	4	1	–	2	3	–	–	1	–	–	1	10	9	–
		1959																	–	2	3	–	–	8	3	–	+	6	2	–	9	6	2	–
		1960													–	5	13	–	–	1	1	+	–	2	3	–	–	17	2	–	+	39	4	–
	50	1956																					8	14	4	–	1	6	1	–				
		1957													–	–	17	1					14	3	4	–	25	5	–	–	1	3	1	–
		1958																		2	2	-					25	1	1					
		1959																									2	17	5	-				
		1960													–	1	12	–	2	8	7	+	4	16	5	–	–	12	4	–	2	18	1	–
	48	1956																																
		1957													5	4	4	–	1	6	–	–									2	10	2	–
		1958																					1											
		1959																									+	2	1					
		1960													–	3	3	–									–	1	1	–	–	5	1	–
	46	1960																									–	2	1	–				

y research vessels, 1956–1960, by month and statistical area.

Longitude																															
170°W				165°W				160°W				155°W				150°W				145°W				140°W				135°W				130°W			
2	3	4		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
																				+	5	5	–												
																												–	2	2	–				
																–	7	3	–	2	4	6	–												
																												8	–	–	–				
																												–	1	1	–				
	2	–	–																																
	2	2	–																																
									–	2	–	–																								
																				1	9	+	–					–	+	–	–		+	+	–	–
–	14	6	–																	2	6	2	+												
																				1	2	–	–										+	–	–	–
																				+	16	26	+												
–	14	2	–																																
–	327	72	3																																
–	18	32	–																																
–	1	1	–																																
–	20	22	–																		2	–	–					–	2	2	–				
2	10	4	–									2	16	8	–	+	11	8	–	–	4	1	+					1	1	+	–				
1	27	8	–									2	13	4	–																				
4	88	5	–																																
									6	5	2	–																								
+	41	3	–																																
2	10	2	–									8	2	–	–					–	5	1	–					–	8	–	–				
												6	5	+	+																				
–	4	–	–						18	5	+	–	26	3	–	–																				
																				3	4	–	–					3	–	–	–				

Continued . . .

Table 19.

Month	Lat. (°N)	Year	Longitude																									
			150°E				155°E				160°E				165°E				170°E				175°E				180				175°W			
			1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
July	60	1956																													–	1	1	
	58	1956																									3	4	1	–	1	2	1	
		1957													22	9	10	–																
		1959																	1	4	1		1	6	+	–	–	3						
		1960													32	14	2	–	5	17	1													
	56	1956																									2	2	1					
		1957																					4	3	–			3	–			2		
		1960									6	15	4	–					4	12	1													
	54	1956																									2	4	6	–				
		1957																					–	–	1		72	2	1	–				
		1958																	1	+	+	–	4	1	1	–								
		1959																					1	2	1	–					–	2	1	
		1960									69	30	2	–																				
	52	1956																									–	3	1	–				
		1957									2	8	9		5	11	2		8	18	6	–	–	–	1	–					–	1		
		1958																					5	+	+	–	2	1	+	–	–	1	+	–
		1959	+	1	2	–													1	–	1	–										1	1	
		1960																	5	15	2											4	1	–
	50	1956																																
		1957									2	6	4	1									1	2	–		3	11	1	–	–	1		
		1958																					10	3	1		6	2	2		4	4		
		1959																	3	3	1	–	10	7		–	157	18	2	–				
		1960																	6	12	1	–	7	29	2		2	11	2	–	8	18	4	4
	48	1956																																
		1958																					1	2	–	–					3	1	–	
		1959																																
		1960		6	6	–																					4	1						
	46	1956																																
August	58	1956																																
		1957																																
		1959													18	4	1	–	16	32	4	–												
	56	1956																																
		1957																					5	8	2	–								
		1959													4	2	–	–	2	18	+	–												
		1960													1	1	–	–	12	10	1	–												
	54	1956																														4	–	
		1957																					1	1	1	–					1	1	1	
		1958																																
		1959									3	10	1	–	3	26	3	–	4	3	+	–												
		1960													2	9	1	–																
	52	1956																																
		1957									4	16	6	–	2	13	3	–					24	8	1	–		1	–	–		1	–	
		1958																													2	+	+	
		1959													1	35	1	–																
		1960													4	16	1	–																
	50	1956																					16	46	2	–	30	18	+	–	7	25	1	–
		1957													4	16	6	–					8	22	1	–	16	17	1	–				
		1958																													29	7	2	–
		1959													–	12	–	–													83	29	1	–
		1960													–	4	–	–	–	4	–	–	13	22	1	–	16	32	2	–				
	48	1956																													1	1		
		1957																													3	18	1	–
		1958																													9	5	1	
		1959																													5	1	–	

Continued.

Longitude																															
170 W				165°W				160°W				155°W				150°W				145°W				140°W				135°W				130°W			
2	3	4		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
																–	–	1	–	+	2	2	–	1	4	3	–								
																				–	4	3	–												
																3	7	–	–	3	–	2	–	+	2	1	–								
–	–	–	–	3	3	–																													
												4	14	5	–	2	3	1	–	2	1	1	–	–	2	–	–								
								15	9	3	–	3	12	2	–													1	2	1	–						
												10	8	–	-					1	6	1	1												
												2	6	2	–	2	3	+	–	3	1	1	–	–	5	2	–	–	5	–	–				
				10	8	1	–	9	22	1	–	4	1	–	–																				
																												–	3	1	–				
12	1	–		92	18	2	–	17	1	+	–																								
4	2	–																																	
												6	5	–	–	7	3	+	–	+	+	1	–												
				1	1	–	–	1	2	1	–	2	–	–	–											4	13	–	–	2	12	1	-			
																				–	1	–	–												
																												–	3	2	–				
11	2	–		5	3	1	–	59	14	1	–																								
17	2	–																																	
												1	–	–	–	2	1	–	–	–	+	–	–												
1	–	–		3	4	+	–	–	2	+	–																								
				1	–	–	–																												
–	+	-						–	–	1	–					–	3	1	–	–	2	1	–												
																				-	1	–	–												
1	–	–		–	+	–	–									–	4	1	–	–	1	+	–	–	+	+	–								
								1	5	1	–	3	10	1	–	4	5	–	-	–	4	+	–												
-	1	–	–	1	1	–						2	1	–	–					1	–	–	–					–	2	–	–				
												–	2	–	–													–	+	–	–				
												–	3	–	–																				
																–	1	1	–																
	1	-	–									-	13	–	–	6	22	1	–																
																				+	+	–	–											–	48	5	–
	2	2	+	–																															
	4	1	–	4	10	1	–	–	1	1	–													–	2	–	–								
												2	4	2	–																				
	5	+	–	2	2	+	–					1	6	–	–	10	4	–	–																
				1	2	–	–																														
3	8	+	+	2	8	+	–									1	–	–	–																
				+	-	–	–																												
	4	1																																	

has spent at sea. All sockeye caught by research vessels are represented by 1-, 2-, 3-, or 4-winter-ocean ages. Virtually all 1-winter-ocean fish are immature. Two-winter-ocean fish include both immature and maturing individuals. Three-winter-ocean fish are mainly maturing. Four-winter-ocean fish are all maturing. Relative abundance values are shown for each ocean age. Index values under 11 are classified as low; 11 to 20, medium; 21 to 30, high; and over 30, very high.

Treatment of the data is by month from May through August (April and September data are scanty). In each month, 1-winter-ocean age is discussed first, followed by succeeding ages up to 4-winter-ocean age. Research vessel biological data from Japan are lacking for the years 1956 and 1958.

In May, sparse sampling showed sockeye of 1-winter-ocean age to be few in number and located mainly in the southern areas of the Gulf of Alaska. Two-winter-ocean fish were more widespread, being caught in most areas fished, and were only slightly more numerous than one-winter-ocean fish. In 1959 and 1960, however, south of the eastern Aleutian Islands, fish of the former age group were present in medium levels of abundance. Three-winter-ocean fish were present in medium to high abundance levels in areas south and west of Attu Island in 1957. Four-winter-ocean fish were rarely caught, and only in waters off the Aleutian Islands.

In June, abundance levels of 1-winter-ocean fish increased from May levels. One-winter-ocean fish were most numerous in southern latitudes, especially directly south of Adak Island in 1957 and 1958, and south of Kodiak Island (area W5550) in 1959, where high abundance levels were reached. A medium abundance level was recorded in 1959 south of the Alaska Peninsula (area W6050). Small numbers were taken at scattered locations throughout the sampling regions.

Two-winter-ocean fish in June increased sharply in abundance from May. They were present in all areas fished, including the northern central Bering Sea. Very high levels were noted in the eastern Bering Sea in 1956, 1957 and 1960 and also in the eastern Aleutians in 1960. Medium abundance levels were noted directly south of the Aleutians (especially in 1960), in the central Bering Sea (1957 and 1960), and in the northwestern areas of the Gulf of Alaska (1958 and 1959).

Three-winter-ocean fish in June increased markedly from May levels, especially in 1957. Very high levels were reached in certain areas of the Eastern and Central Bering Sea regions in 1957. Medium levels were noted west and southwest of Attu Island in 1957. In 1956, a very high level of 3-winter-ocean fish was recorded in the eastern Bering Sea (area W7056), but this was the result of a single, unusually large net haul in which 2-winter-ocean fish predominated. In scattered sampling throughout the Gulf of Alaska, 3-winter-ocean fish were in low abundance or were absent, except to the north (area W 4558) in 1957, where a high level was noted.

Four-winter-ocean fish, still very few in number, were caught mainly west of Longitude 175°E.

In July, in each year, 1-winter-ocean fish increased strikingly in their relative abundance, especially in 1959. In that year, the highest abundance level ever recorded for 1-winter-ocean fish was encountered directly south of Adak Island. Abundance levels were also very high south of the Alaska Peninsula. In 1960, very high levels of abundance were noted east of Kamchatka (area E6054) particularly, and south of the eastern Aleutians (area W7050). High levels of abundance also occurred in the western Bering Sea. In 1957, 1-winter-ocean fish were at very high abundance levels in the central Bering Sea. Their numbers decreased to medium levels westward into the western Bering Sea. In the southern areas of the Okhotsk Sea, 1-winter-ocean fish were apparently absent in July (1959 and 1960).

Two-winter-ocean sockeye in July were most abundant in 1960. In 1960, high levels were recorded in two areas, one off eastern Kamchatka, the other south of the western Aleutians. Medium abundance levels were also recorded from several areas in the western Bering Sea and south of the entire Aleutian Island chain. Medium levels in other years were noted west of Attu Island (1957), south of Adak Island (1957 and 1959), south of the eastern Aleutians (1959) and the Alaska Peninsula (1957 and 1959), south of Kodiak Island (1956 and 1957) and west of the northern tip of Vancouver Island (1957). In the southern Okhotsk Sea, abundance levels were very low.

Three-winter-ocean fish in July were in relatively low abundance, especially in offshore areas. Highest abundance levels were noted off southeast Kamchatka and off Karaginski Island in 1957.

Four-winter-ocean fish were virtually absent.

In August, a very high abundance level of 1-winter-ocean fish was noted in 1959 southeast of Adak Island (area W7550). High abundance levels were recorded south of Adak Island in 1956, east of Attu Island in

57, and southeast of Attu Island in 1958. Medium
els were noted in areas east of Karaginski Island
957), southeast of Karaginski Island (1960) and
uth of the Aleutians (1956, 1957 and 1960).

Two-winter-ocean sockeye were at very high abun-
nce levels in August southeast of Attu Island in area
550 (1956), south of Adak Island (1960), south of
e Komandorski Islands (1959) and southeast of Cape
iutorski (1959). High abundance levels were noted
uthwest of Attu Island (1957 and 1960), southeast
Adak Island (1956 and 1959) and in the area adjoin-
g the Komandorski Islands (1959). Medium abun-
nce levels were noted in the western Aleutians and
areas south and northeast of the Komandorski
lands in different years. Medium levels were also
ted south and southwest of Kodiak Island (1956).

Three-winter-ocean sockeye in August were in low
undance or were absent throughout the North
acific and Bering Sea. Most were taken in the west-
n Pacific and western Bering Sea.

In September, sampling was very sparse and was
nfined mainly to the eastern Pacific. Sockeye
tches were small. One- and 2-winter-ocean sockeye
ly were caught.

(b) Total Age.

In Section IV, the consistency of age determinations
r sockeye salmon was assessed by comparing the scale
adings by the three national Scale Reading Groups.
greement in readings was lower for total age (76.1%)
an for ocean age (96.3%). The difference in agree-
ent was due to different interpretations of the fresh-
ater age zones when determining total age. It was
ncluded, however, that total age determinations
ere sufficiently reliable to warrant acceptance.

Appendix Table B presents the ages of sockeye,
ccording to date and statistical area, caught by INPFC research vessels in the various years. The data are not weighted for variation in the amounts of gillnet of different mesh sizes fished. In some cases, age determinations were obtained from part of the catch only.

The system of designating sockeye ages was explained in Section IV. Most of the sockeye taken by research vessels had left fresh water in their second or third year of life and had spent one, two or three winters in the ocean. The major age groups were 3_2, 4_3, 4_2, 5_3, 5_2 and 6_3.

Table 20 lists the unweighted numbers of sockeye salmon in the major age groups according to 10-degree intervals of longitude across the North Pacific and Bering Sea for the years 1956–1960 combined (from Appendix Table B). A total of 24,868 sockeye salmon is represented.

Figure 15 shows the distribution of 1-year-freshwater and 2-year-freshwater sockeye of 1-, 2- and 3-winter-ocean ages by 10-degree intervals of longitude. The figure is based on data for the years 1956–1960. Two-year-freshwater sockeye were dominant in the western longitudes, 1-year-freshwater sockeye in the eastern longitudes. The transition in dominance of the two freshwater age groups from east to west was consistent and evident in 1-winter-ocean fish (3_2's and 4_3's), 2-winter-ocean fish (4_2's and 5_3's) and 3-winter-ocean fish (5_2's and 6_3's).

Bias from gillnet selectivity is not considered important in establishing the above relationship. The comparison is between 3_2 and 4_3 fish, between 4_2 and 5_3 fish and between 5_2 and 6_3 fish. Within each of the three ocean age groups, the size distribution of the two freshwater ages is most likely very similar, i.e., 4_2's are about the same size as 5_3's (see later section on sockeye sizes).

TABLE 20. Sockeye salmon of major age groups from unweighted research vessel catches by 10-degree intervals of longitude, North Pacific and Bering Sea, for the years 1956–1960 combined.

	10-degree interval of longitude (mid-point)								
Total age	160° E	170° E	180°	170° W	160° W	150° W	140° W	130° W	Total
3_2	20	126	755	375	472	419	97	40	2,304
4_3	107	264	717	384	168	144	14	2	1,800
4_2	91	699	3,752	3,245	593	758	493	363	9,994
5_3	161	697	2,609	1,894	561	297	202	30	6,451
5_2	27	236	512	778	77	169	358	75	2,232
6_3	98	303	667	774	70	69	103	3	2,087
Total	504	2,325	9,012	7,450	1,941	1,856	1,267	513	24,868

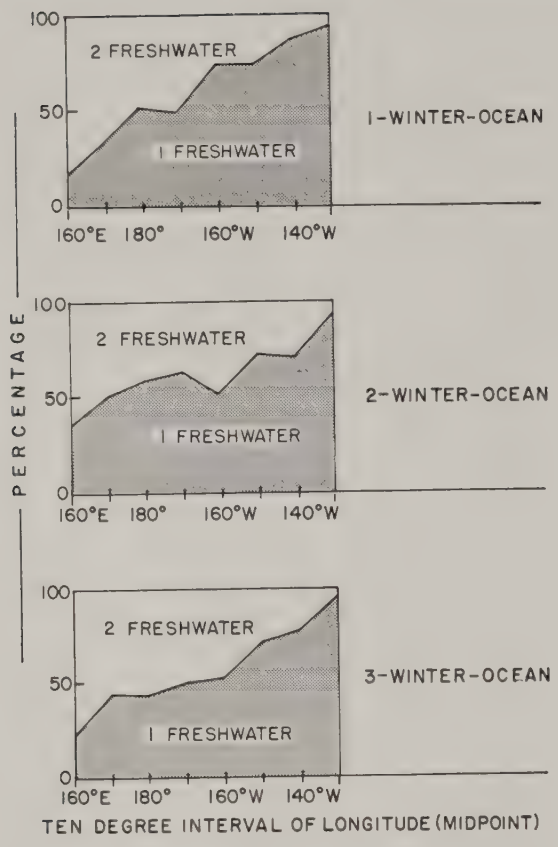

FIGURE 15. Percentage of sockeye salmon of various ages, by 10 degrees of longitude, INPFC research vessel data, 1956–1960.

2. *Mothership Operations*

The total age composition (in percent) of sockeye salmon samples from the mothership catches is shown by fishery region for monthly periods of 1956 to 1960 in Figure 16. Supplementary data for statistical areas for selected 10-day periods of 1956 to 1958 are shown in Figure 17. Since the data are presented on a percentage basis without regard to relative abundance of sockeye, the results are qualitative, not quantitative.

Information on age composition of the available salmon is subject to several sources of error. The extent of errors in aging sockeye salmon by misinterpretation of scale patterns has already been discussed.

Another possible source of error is in the sampling by gillnets of 4.8″ mesh used by the mothership fishery. As mentioned in Section V, gillnets of 4.8″ mesh are suitable for catching sockeye of 2- and 3-winter-ocean ages, but are completely ineffective for taking small, 1-winter-ocean sockeye (less than 40 cm). Accordingly, it is not possible to estimate from the mothership catches the proportion of the 1-winter-ocean age group in the available population. It is possible, however, to correct for bias resulting from mesh selectivity in the older age groups caught, using efficiency values shown in Table 8 and size composition by age shown in Appendix Table G.

Table 21 gives two examples comparing age composition in the catches of gillnets of 4.8″ mesh with estimated age composition in the available population. No large discrepancies are evident in this comparison. Therefore, the age compositions of sockeye salmon shown for the mothership fishery are believed to be reasonable estimates of the available population, excluding 1-winter-ocean sockeye.

The age composition of sockeye salmon in 1956 by fishery region is shown in Figure 16. In the large region east and southeast of Kamchatka and west of Longitude 170°E (mainly North Pacific), the main age groups in May, in order of importance, were 6_3 (31%), 5_2 (24%) and 5_3 (19%). Minor age groups included 4_2, 7_4 and 6_4. Successively through the months into August, the percentages of older (3-winter-ocean) fish decreased, while the percentages of younger (2-winter-ocean) fish increased. The dominant age groups in August were 5_3 (45%) and 4_2 (30%).

In the region east of Longitude 170°E, the May samples represent sockeye caught south of the Aleutian Islands, principally in areas E7050 and E7048. Sockeye of age 6_3 (30%) and age 5_3 (28%) were about equally dominant, followed by 5_2's (21%) and 4_2's (13%). Ages 7_4 and 6_4 occurred in lower percentages than west of Longitude 170°E. In June, in catches over a broad area south and southwest of the Aleutians and extending into the central Bering Sea, 5_3 fish replaced 6_3 fish as the main age group (34%) and the proportion of 4_2 fish also increased to second in rank (24%). In July, the proportion of 5_3 fish increased further to 41%, that of 4_2 fish remained unchanged, and that of 6_3 fish decreased.

In the Okhotsk Sea, during the entire fishing period, 6_3 fish dominated the samples (34%), followed closely by 5_3 fish. Fish of ages 5_2 and 5_3 were equally important in June. During July and August, the proportions of 5_2 and 4_2 fish declined; those of older fish, namely 6_4's and 7_4's, increased.

The age composition of catches in each statistical area during late June and early July 1956 (Figure 17) provides more detailed information on the distribution and relative importance of various age groups. In

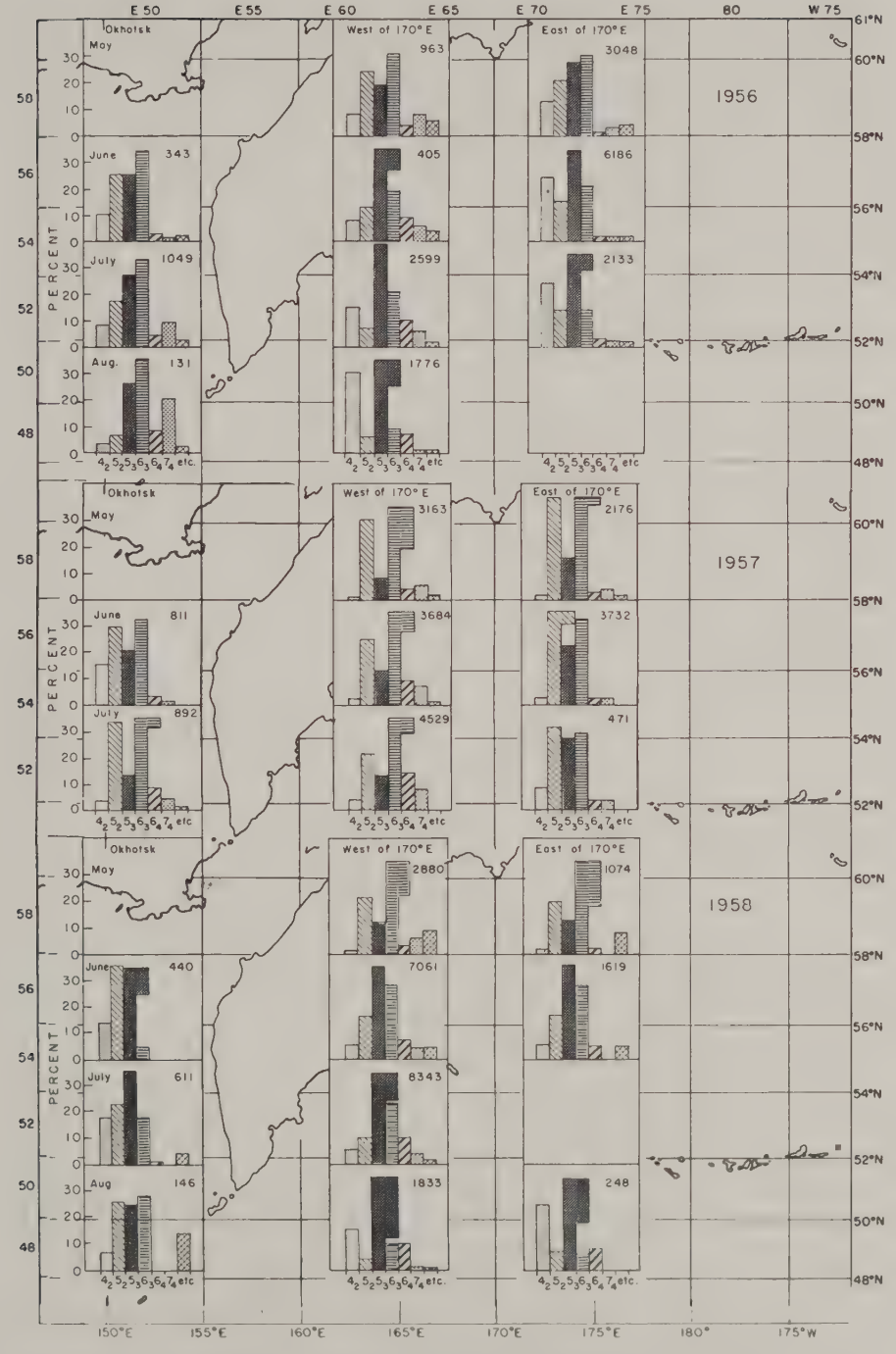

FIGURE 16. Age composition (percent) of sockeye salmon samples from the mothership fishery, by region and by month, 1956–1960. Numbers for each month represent sample size.

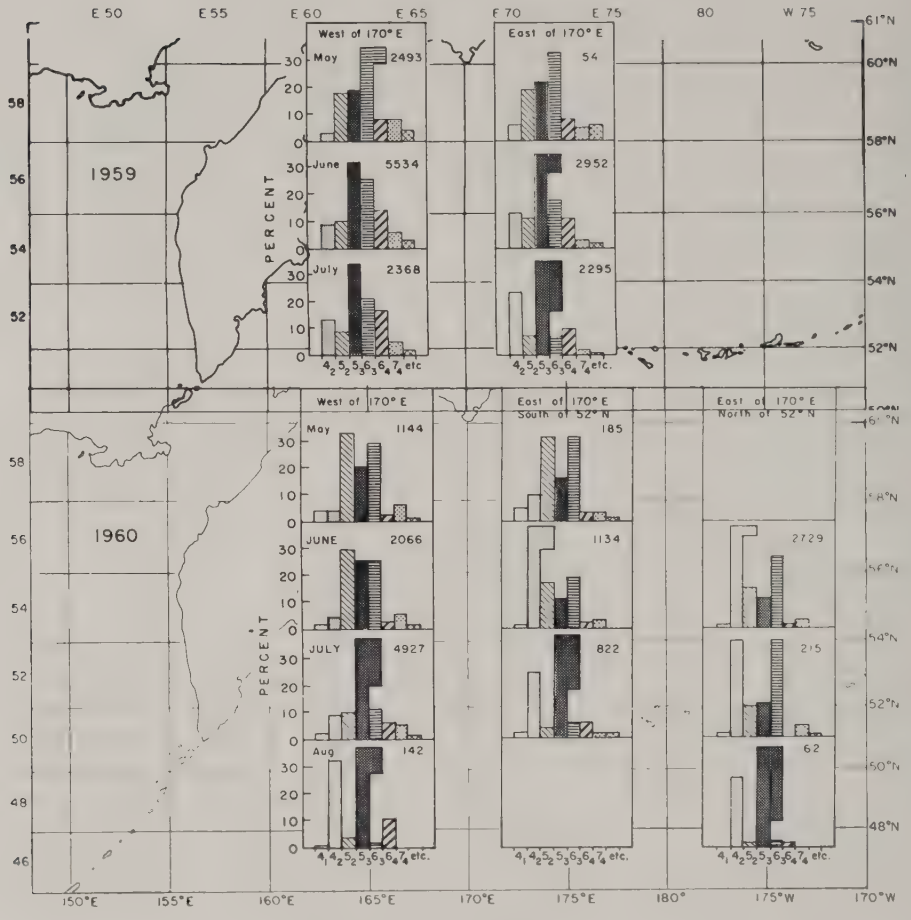

FIGURE 16. Continued.

late June, west of Longitude 175°E, 5_3 and 6_3 fish were most important. East of 175°E, 4_2's were predominant, followed closely by 5_3's. In early July, 5_3's predominated west of Longitude 175°E, while east of Longitude 175°E, 4_2 and 5_3 fish were most important. Considering both time periods, the percentage of 4_2's was much higher in the east and the percentage of 6_3's was higher in the west. In the Okhotsk Sea, during both periods, 6_3 was the main age group.

In 1957, west of Longitude 170°E in the North Pacific in May, 6_3 was the dominant age group (51%), followed by 5_2 (30%) (Figure 16). Through the fishing period, the importance of these two age groups declined only slightly and they were still dominant in July when fishing ceased. The proportions of fish of ages 5_3, 6_4, 7_4 and 4_2 increased slightly during July.

East of Longitude 170°E in May, the age composition pattern of sockeye was similar to that west of Longitude 170°E, except for a somewhat lower percentage of 6_3's (41%) and a higher percentage of 5_2's (38%). These samples were from southwest of the Aleutians. In June, when fishing expanded into the central Bering Sea, 5_2's were dominant (40%), followed by 6_3's (32%), while west of Longitude 170°E, 6_3's were dominant (42%), followed by 5_2's (25%). In July, 5_2's (31%), 6_3's (29%) and 5_3's (27%) were nearly equal in importance east of 170°E.

In the Okhotsk Sea in June, 6_3's (32%) and 5_2's (29%) were dominant. Fish of ages 5_3 and 4_2 were also important. In July, the older age groups, comprised mainly of 3-winter-ocean fish, were relatively more numerous than in June.

In 1957, information on age composition by statistical areas is available for the mid-June and late June periods (Figure 17). In mid-June, 6_3's dominated in

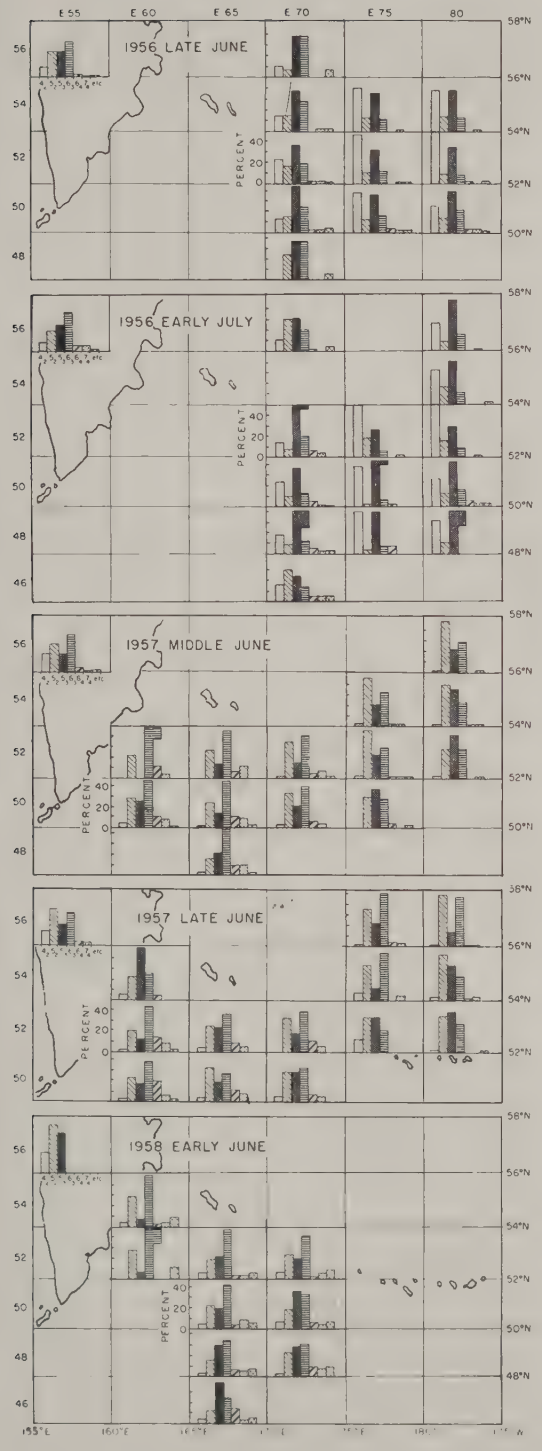

FIGURE 17. Age composition (percent) of sockeye salmon samples from the mothership fishery, by statistical area and selected 10-day periods, 1956–1958.

the western areas and gradually decreased in importance eastward. Although 7_4's and 6_4's were less numerous than 6_3's, a similar tendency was observed for these ages. The percentages of 5_2's and 5_3's, on the other hand, increased eastward. Samples from the eastern part of the Bering Sea fishery showed that 5_2's were dominant in northern waters, 5_3's in southern waters. Sockeye of age 6_3, while not as numerous as west of Longitude 170°E, nevertheless were present in proportionately high numbers. There was little change between mid-June and late June in the age composition of sockeye in the various statistical areas. The greatest change noted was in the northern central Bering Sea where the percentage of 6_3's increased.

In the Okhotsk Sea, 6_3 and 5_2 were the important age groups in mid and late June 1957.

In 1958, motherships operated in the North Pacific mainly west of Longitude 170°E. They did not extend into the Bering Sea. Age composition was quite similar east and west of Longitude 170°E (Figure 16). In May, 6_3 was by far the most important single age group (48%–52%), followed by 5_2 (20%–21%). Through the season the percentages of these ages decreased. During the same period, percentages of 5_3's and 4_2's increased, 5_3's being numerous in August (52%–58%).

In the Okhotsk Sea, sockeye salmon catches in 1958 were very low. In June, 5_3's were dominant (45%), followed by 5_2's (36%). In August, 6_3's, 5_2's and 5_3's were about equal in importance (25%–28%).

Comparing the age composition of sockeye caught in different statistical areas in early June 1958 (Figure 17) in the northern and western areas of the North Pacific, the dominant age group was 6_3, followed by 5_2. In the southeastern areas, 5_3's were equally important as 6_3's, followed by 5_2's.

In 1959, in the North Pacific in May, the age composition was quite similar for the regions east and west of Longitude 170°E (Figure 16). Sockeye of age 6_3 were dominant, slightly more so in the western part, followed by 5_3's and 5_2's. The proportion of fish of age 6_3, along with those of 5_2's and 7_4's, decreased through June and July, while those of 5_3's, 4_2's and 6_4's increased. In July, the percentages of 5_3's and 4_2's were much higher east of Longitude 170°E than west of this meridian. West of Longitude 170°E, 6_3's and 6_4's were more numerous.

In 1960, west of Longitude 170°E, May and June samples showed in order of rank a predominance of 5_2's, 6_3's and 5_3's (Figure 16). In July, the 5_3's were

TABLE 21. Age composition of sockeye salmon samples from mothership catches and estimated age composition in available population.

Region and time period	Total age composition (percent)						
	4_2	5_2	5_3	6_3	6_4	7_4	Others
East of 170° E, June 1957							
in sample	2	40	22	32	2	2	—
estimated	2	40	21	33	2	2	—
East of 170° E, North of 52° N, June 1960							
in sample	42	15	11	27	1	3	1
estimated	41	16	10	28	1	3	1

particularly numerous (56%). In August, 5_3 (49%), followed by 4_2 (33%), were the main age groups.

East of Longitude 170°E and south of Latitude 52°N, the age composition in May was similar to that for the region west of Longitude 170°E. However, in the large June catches, 4_2's predominated (47%) and 5_2's and 6_3's were much less important. In July, the percentage of 5_3's (59%) increased greatly and predominated. Fish of age 4_2 (24%) were much less numerous than in June.

East of Longitude 170°E and north of Latitude 52°N, mainly in the eastern part of the central Bering Sea, in June, 4_2's predominated (42%), followed by 6_3's (27%). In July, fish of these ages were equally represented in the catches (36% and 35%, respectively). In August, a small sample showed 5_3's to be largely dominant (66%), followed by 4_2's (27%).

3. *Landbased Region Operations*

Information on age composition of sockeye salmon in the landbased fishing region is available from very small samples collected in 1960 by research vessels fishing with commercial gear (4.5″ mesh) south of Latitude 45°N in May and June and north of Latitude 45°N in July and August. In each month, several age groups were present in the catches, but 5_3's were dominant.

4. *Summary*

The major sockeye salmon age groups taken by research vessels were 3_2, 4_3, 4_2, 5_3, 5_2 and 6_3. Except for 3_2 and 4_3 fish (1-winter-ocean), which were not vulnerable to capture by commercial gillnets, mothership operations caught the same age groups as did research vessels. Catches by both operations showed the various age groups to vary in relative importance both seasonally and annually in the areas fished.

According to research vessel catches, the proportion of 2- and 1-year-freshwater sockeye salmon of 1-, 2- and 3-winter-ocean ages formed a consistent, definite cline across the North Pacific and the Bering Sea. Two-year-freshwater fish were dominant in the west-ern areas,' 1-year-freshwater fish in the eastern areas.

In May, 1-winter-ocean fish, when taken, mainly appeared in catches from the central Gulf of Alaska. A few individuals occasionally appeared south of the central Aleutians (1959). Two- and 3-winter-ocean fish were present throughout the areas fished by both commercial and research vessels. In the western Pacific, 3-winter-ocean fish were more abundant. Four-winter-ocean fish, rarely caught, were taken only west of Longitude 170°W. Samples of the mothership catches from the North Pacific in all years (1955–1960) showed 6_3 fish to be dominant (except in 1960 when 5_2's were equally dominant) and followed in rank by 5_2's and 5_3's.

During June, 1-winter-ocean sockeye were more numerous and more widespread than in May. They were most abundant south of the Aleutians (1957, 1958) and the Alaska Peninsula (1959).

Two- and 3-winter-ocean sockeye were much more numerous than in May, occurring in most areas fished by both research and commercial vessels, even as far north as the northern areas of the Bering Sea. In June, 3-winter-ocean fish (6_3's and 5_2's) were supplanted in importance by 2-winter-ocean fish (5_3's and 4_2's) in all regions and all years except 1957. In 1957, 3-winter-ocean fish continued their dominance from May with 6_3's being dominant in the western Pacific, mainly west of Longitude 175°E, and 5_3's being dominant in the Central Bering Sea region. In other years, major areas of concentration of 2-winter-ocean fish (4_2's and 5_3's) were usually located in the central and eastern Aleutians, Central and Eastern Bering Sea regions and in the western and northern Gulf of Alaska (1957, 1959, 1960). Also, in the Gulf of Alaska, 3-winter-ocean fish appeared to be less

abundant than elsewhere and mainly occurred in the northern areas. Four-winter-ocean fish were few in number and largely present west of Longitude 175°E.

In July, the numbers of 1-winter-ocean fish increased markedly south of the Aleutians and the Alaska Peninsula especially, and in the western areas of the North Pacific and Western Bering Sea region as well. Commercial fishery samples indicated that 2-winter-ocean fish increased further in relative importance over 3-winter-ocean fish. Three-winter-ocean fish, however, increased in relative importance shoreward while 2-winter-ocean fish increased in relative importance offshore. This was also suggested by research vessels operating in 1958 in the western Pacific and Bering Sea. In 1960, commercial fishery samples from the Bering Sea indicated 4_2 and 6_3 fish to be equally dominant and relatively more important than in other regions. In the Gulf of Alaska, considering all years, 2- and 3-winter-ocean sockeye were low in relative abundance and most numerous in peripheral areas.

In August, 1-winter-ocean fish continued to increase over July levels. The centers of abundance were mainly located in the northern areas of the Western Bering Sea region and south of the Aleutian Islands. Also, in some years they were present in moderate numbers in southern areas of the Western Gulf of Alaska region. They were virtually absent in all years in the areas fished in the eastern half of the Bering Sea.

The relative importance of 2-winter-ocean fish (5_3's mainly and 4_2's) in August was still greater than in July, indicating that 3-winter-ocean fish had virtually disappeared from the high seas areas. The main centers of 2-winter-ocean fish, according to research vessels, were located in the Western Bering Sea region and waters of the western North Pacific eastward south of the Aleutians into the Western Gulf of Alaska region.

In the Okhotsk Sea, samples of commercial catches indicated that 3-winter-ocean sockeye formed the major portion of the catch throughout the fishing season in each year. From June into August, the proportion of older fish increased while that of younger fish decreased.

D. Length and Sex of Sockeye Salmon in Mothership Catches

1. *Length*

The fork length frequency distributions and mean fork lengths of sockeye salmon in samples taken from the mothership fishery in the years 1957 to 1960 are shown in Appendix Table G. The length data are given by region of catch, by age group, by sex and by month. In 1960 only, the region east of Longitude 170°E was separated into the Bering Sea and Aleutian regions by Latitude 52°N; in other years these two regions were combined. Okhotsk Sea samples are given for 1957 and 1958 only, since the fishery did not operate there in 1959 and 1960. The region west of Longitude 170°E included the fishing grounds in the northwest Pacific and western Bering Sea.

No attempt to fully analyze the large amount of length frequency data is made in this report. Only salient qualitative features are pointed out. To facilitate the discovery of these features, the mean lengths of 2- and 3-winter-ocean sockeye salmon are summarized in Table 22. The mean lengths are given to the closest centimeter by year, by month, by region, by sex and by age. In pointing out features, it must be realized that the sizes of fish of the same age can be variously influenced by environmental conditions, by genetic characteristics linked with origin and by changes in size and shape as secondary sexual characteristics develop with approaching maturity. Furthermore, the data are from samples of catches made by gillnets which are selective for size of fish. The 4.8″ mesh gillnets tend to select the larger 2-winter-ocean sockeye and the smaller 3-winter-ocean sockeye.

Table 22 shows the following features:

Females are slightly smaller than males, usually 1 cm to 2 cm for all ages in all regions. In some cases, the sexes are about the same size. The difference in lengths between females and males is slightly greater in 3-winter-ocean fish than in 2-winter-ocean fish.

Two-winter-ocean fish appear to be about 4 to 6 cm smaller on the average than 3-winter-ocean fish (4–5 cm in females, 5–6 cm in males). These average values are cursory and do not account for the range of differences in mean lengths.

Two-winter-ocean sockeye of various ages (4_2's, 5_3's and 6_4's) appear to differ only slightly in length. Fish of age 4_2 are about 1 cm smaller than 5_3's or 6_4's; the latter two age groups have about the same mean lengths. Also, the age groups with three winters at sea (5_2, 6_3 and 7_4) show no consistent differences in length.

In the region south of the Aleutians and east of Longitude 170°E in 1960, 2-winter-ocean fish decreased

TABLE 22. Mean fork lengths (cm) of sockeye salmon in samples of mothership catches, by region, age and month, 1957–1960.

			Female			Male			Female			Male		
Year	Month	Region	4_2	5_3	6_4	4_2	5_3	6_4	5_3	6_3	7_4	5_2	6_3	7_4
1957	May	E of 170° E	—	52	52*	—	53	51	55	55	54	57	57	55
		W of 170° E	50	51	50	50	52	51	54	54	54	56	55	55
	June	E of 170° E	52	53	52	52	54	53	57	57	57	59	58	58
		W of 170° E	50	51	51	50	51	52	54	54	54	56	56	56
		Okhotsk	51	51	—	53	53	53*	56	56	—	58	58	—
	July	E of 170° E	49*	52	—	49	51	—	56	57	—	57	57	—
		W of 170° E	50	51	51	51	52	52	55	55	55	56	56	56
		Okhotsk	52*	52	52	53*	53	53	56	56	56	59	57	58*
1958	May	E of 170° E	—	51	52*	49*	51	—	55	55	55	57	57	57
		W of 170° E	51	51	52	51	52	52	54	54	54	57	56	56
	June	E of 170° E	51	51	52	51	52	52	56	56	56	57	58	57
		W of 170° E	50	51	51	50	52	52	55	55	55	57	57	57
		Okhotsk	49	49	—	49	50	—	54	60*	—	56	55*	—
	July	W of 170° E	50	52	52	51	52	52	57	57	57	59	58	59
		Okhotsk	52	52	—	52	54	—	57	57	—	60	59	—
	Aug.	E of 170° E	49	51	—	52	52	50*	—	—	—	57	—	—
		W of 170° E	50	50	51	50	52	52	55	56	56*	55	56	—
		Okhotsk	—	53	—	—	—	—	58	58	—	62*	60*	—
1959	May	E of 170° E	51*	52	52	54*	54	52	55	56	55*	56	58	58*
		W of 170° E	51	52	52	53	53	53	56	56	56	57	58	57
	June	E of 170° E	51	52	52	51	52	52	55	56	55	56	57	56
		W of 170° E	50	51	52	50	52	53	56	57	56	57	58	58
	July	E of 170° E	50	50	52	51	51	52	56	58	57	58	59	59*
		W of 170° E	50	52	52	50	52	52	56	58	59	58	59	60
1960	May	E of 170° E, S of 52° N	—	—	—	54*	52	—	56	58	—	60	59	—
		W of 170° E	54*	51	—	53	53	51*	55	56	57	58	59	58
	June	E of 170° E, S of 52° N	52	52	—	53	54	54*	56	57	57	59	59	57*
		E of 170° E, N of 52° N	52	54	54*	54	55	55*	58	58	59	60	60	60
		W of 170° E	51	52	52	52	53	53	56	57	58	59	60	60
	July	E of 170° E, S of 52° N	49	50	52*	50	51	52	57	59	—	—	56*	—
		E of 170° E, N of 52° N	52	53*	—	54	55*	—	58*	59	—	—	60*	—
		W of 170° E	50	52	52	50	53	53	57	58	58	58	60	60
	Aug.	E of 170° E, N of 52° N	—	50*	—	—	49	—	—	—	—	—	—	—
		W of 170° E	49*	49	—	50	52	53*	—	—	—	—	—	—

* Small samples of 10 to 19 fish. Samples under 10 were excluded.

in length from June to July. Females of age 4_2 decreased from 52 cm to 49 cm, males from 53 cm to 50 cm. Females of age 5_3 decreased from 52 cm to 50 cm, males from 54 cm to 51 cm. Small samples of 6_4's also showed this trend. Decreases in length from June to July were also noted for 4_2's and 5_3's in 1957 and for 5_3's in 1959 in the region east of Longitude 170°E. These decreases in length appear to be related to the replacement of maturing fish by immatures.

During June of 1957, sockeye salmon east of Longitude 170°E were larger than sockeye salmon west of Longitude 170°E. This difference was noted in all major age groups, namely 4_2, 5_3, 6_4, 5_2, 6_3 and 7_4, in both sexes. The difference in size averaged about 2 cm, ranging from 1 to 3 cm for each age group.

Bering Sea samples of 5_3 sockeye in 1960 showed little change in length from June to July, but showed a decrease in August (August samples were small).

Two-winter-ocean sockeye from the Bering Sea during June and July 1960 were about 2 cm larger than sockeye from west of Longitude 170°E.

West of Longitude 170°E, 5_2's, 6_3's and 7_4's usually showed slight increases in length from June to July, presumably attributable to growth.

In the Okhotsk Sea, 4_2's, 5_3's and 5_2's increased about

3 cm in length from June to July in 1958. In 1957, these age groups showed little change in length from June to July.

2. *Sex*

General qualitative features only of the distribution of male and female sockeye salmon, as shown by samples from the mothership fishery, are pointed out in this report. This distribution by sex is shown in terms of percentage of males. Table 23 summarizes sex ratio data from Appendix Table G according to ocean age, region, month and year. The table is not corrected for effects of gillnet selectivity on sex ratio, but such effects are considered minor, since sexual dimorphism does not exist in salmon on the high seas to any appreciable extent.

TABLE 23. Percentage of male sockeye salmon in samples of mothership catches, by ocean age, region and month, 1957–1960.

Year	Region	Month	Ocean age			
			2-winter-ocean	3-winter-ocean	4-winter-ocean	All samples
1957	East of 170° E	May	52	45	—	
		June	47	39	—	
		July	55	43	—	
	West of 170° E	May	54	41	—	
		June	59	41	—	
		July	54	40	—	
	Okhotsk	June	68	52	—	
		July	52	27	—	
		All samples	54	41	—	44
1958	East of 170° E	May	64	40	—	
		June	50	38	—	
		July	69	—	—	
	West of 170° E	May	71	44	31	
		June	55	35	26	
		July	49	38	33	
		Aug.	58	43	—	
	Okhotsk	June	55	32	—	
		July	36	41	—	
		All samples	53	38	29	46
1959	East of 170° E	May	50	29	—	
		June	58	30	—	
		July	61	43	—	
	West of 170° E	May	56	32	—	
		June	56	29	—	
		July	60	36	—	
		All samples	58	32	—	47
1960	East of 170° E, South of 52° N	May	—	44	—	
		June	69	40	—	
		July	66	—	—	
	East of 170° E, North of 52° N	June	65	34	—	
		July	43	23	—	
	West of 170° E	May	72	44	—	
		June	64	33	—	
		July	56	32	—	
		Aug.	66	—	—	
		All samples	61	35	—	50

Two general features are apparent from sex ratio data for sockeye salmon caught in mothership operations, even though fishing areas varied annually to some extent (see Figure 13).

(1) Sex ratios changed monthly and regionally. In May, males usually were proportionately more numerous west than east of Longitude 170°E. This regional trend in sex ratios also occurred in 2-winter-ocean fish in June in 1957 and 1958. The increasing dominance of males extended into the Okhotsk Sea in June of 1957, but the reverse was noted for 1958. In July, the proportion of males tended to increase eastward from the Okhotsk Sea to the region east of Longitude 170°E. This was especially apparent in 2-winter-ocean fish.

(2) Sex ratios changed with age of sockeye. In each region and in almost each month in 2-winter-ocean fish, males were proportionately more numerous than females. In 3-winter-ocean fish, however, females were dominant. The disparity favouring females was even greater in 4-winter-ocean fish, according to data obtained from catches made west of 170°E in 1958.

The reasons for the changes in sex ratios described above are not clear from the available data. The higher proportion of males in catches made in regions contiguous to Kamchatka than in catches made east of Longitude 170°E in May and June suggests some differences in the coastward migration times of males and females, with males tending to leave the high seas areas in advance of females. From coastal studies, it is well known that males precede females in their spawning migrations and it is possible that this difference in migration times may have its origin at some considerable distance offshore. The higher proportion of males east than west of Longitude 170°E following June may reflect other factors. In approaches to Kamchatka, the sex ratios may fluctuate more readily as a result of the arrival of several maturing stocks each with different migration times and routes, while offshore, as pointed out earlier, sockeye are increasing in relative numbers as immature fish become more available. Assuming that males grow faster than females, which was shown for western Alaskan sockeye salmon (Lander and Tanonaka, MS 1963), one might expect males, on the average, to be larger than females and thus better represented in the catches, especially in the summer and early fall.

These possible explanations for seasonal variations in sex ratios do not, however, account for the declining proportion of males with increasing ocean age. This phenomenon might be indicative of a differential mortality rate, with males having a higher death rate than females.

E. Recapitulation

Information on the distribution of sockeye salmon on the high seas has been derived from catches by Canadian, Japanese and United States gillnet vessels participating in the INPFC research program and from catches by Japanese motherships and training vessels operating in the landbased region. Examination of the catches revealed annual, seasonal and spatial variations in abundance levels, age composition and importance of immature and maturing individuals. It is quite clear, however, that while these variations occurred, a basic general distribution pattern prevailed and was reasonably similar in most years. This pattern for the period May through August can be described in general terms as follows.

In May, sockeye salmon occur widely in the North Pacific north of a line which, in the western Pacific, is located between Latitudes 42°N and 45°N and, in the eastern Pacific, between Latitudes 47°N and 49°N. Within this territory, sockeye are most concentrated offshore from southwest and south of the Aleutian Islands eastward to south of the Alaska Peninsula and northeastward into the Gulf of Alaska. Their numbers decline in all directions from this large region. Although sockeye are known to occur in the southern Bering Sea in May in some years, the extent or annual consistency of their occurrence in the Bering Sea is not known. Also, it is not known whether they occur in the Okhotsk Sea.

In the southern latitudes, virtually the entire high seas population in May consists of immatures. Northward and coastward from this area their importance in the population decreases. In the western Pacific immediately south of the Aleutian Islands and in the northern Gulf of Alaska, the sockeye populations consist almost exclusively of maturing individuals.

Although sockeye of many ages and life-history groups are present in May, they do not fully intermix. Rather, they are distributed in a somewhat stratified pattern. In the western Pacific, 2-year-freshwater sockeye (that is, sub-threes) dominate, but their importance in the catches decreases eastward and ultimately is superseded by 1-year-freshwater sockeye (sub-twos) in the eastern Pacific. The area where these two groups are approximately equally represented in the catches lies between Longitudes 170°E and 180°. Within this trans-Pacific band, sockeye are further stratified latitudinally according to marine

residence. Except for some overlap between age groups, 3-winter-ocean sockeye tend to occur further north than 2-winter-ocean fish. The latter in turn occur further north than 1-winter-ocean fish. Four-winter-ocean fish, rarely caught, occur mainly in the western half of the Pacific. Considering the number of winters spent in the ocean as being indicative of degree of maturity—that is, 1-winter-ocean fish are immature, 3-winter-ocean fish are maturing and 2-winter-ocean fish include both immature and maturing fish—it is apparent that the distribution pattern of maturing and immature fish derived from age data is reasonably similar to that apparent from maturity studies using gonad and body weight data.

In June, sockeye are more widespread than in May, occurring throughout the Bering Sea and at least southwest of Kamchatka in the Okhotsk Sea, as well as in the North Pacific. Some spatial changes in the relative importance of maturing fish and fish of different ages can also be noted, particularly during the latter part of the month.

In the northwest Pacific, abundance levels in June are about the same as in May, but older, maturing sockeye gradually are replaced by younger, immature individuals. Whereas 3-winter-ocean fish, consisting of 6_3's mainly, and 5_2's, dominated the catches in May, they are replaced in June by 2-winter-ocean fish of ages 5_3 and 4_2. South of the Aleutian Islands and the Alaska Peninsula, sockeye are relatively more abundant than in May and the area of concentration has shifted northward. Catches in these regions consist largely of 2-winter-ocean fish. Immatures are dominant by the end of the month. In the Gulf of Alaska, relative numbers decline from the northwest to the southeast. Maturing, 3-winter-ocean fish are mainly present in northern waters. Offshore and southward, younger, immature fish are more numerous and are dominant in the southwest areas of the Gulf.

In the Bering Sea, sockeye are concentrated in the southern central and eastern areas in June, thus extending the dense concentration of sockeye salmon located south of the Aleutian Islands. As is the case in the North Pacific, several age groups are present. Three-winter-ocean fish dominate in the western Bering Sea, where sockeye are not particularly abundant. Progressively eastward, sockeye are more numerous and usually consist mainly of 2-winter-ocean fish.

In the Okhotsk Sea, sockeye are not particularly abundant in June. Fish here are virtually all maturing and include many age types. Not unlike the western areas of the Pacific Ocean and the Bering Sea, 3-winter-ocean fish dominate, with 6_3 being the most important individual age group, followed by 2-winter-ocean fish.

During July, marked changes occur in the distribution, ages and maturity of sockeye salmon, as maturing individuals evacuate the high seas areas, thus leaving a large residue of immature fish in all areas except those adjacent to coastal spawning areas off the east coast of Kamchatka and North America. Abundance levels in the northwest Pacific increase progressively through the month to relatively high levels and sockeye salmon consist of 3- and 2-winter-ocean fish. Four-winter-ocean sockeye, present in June, are virtually absent. Abundance levels also continue to be relatively high south of the Aleutian Islands and into the western Gulf of Alaska. In these waters, however, sockeye are immature 1- and 2-winter-ocean fish. Further shoreward, abundance levels decline and 2-winter-ocean maturing fish dominate the catches.

In the Bering Sea in July, abundance levels are highest in the western areas and decline rapidly eastward. Whereas sockeye were very abundant in the eastern Bering Sea in June, they are now virtually absent. Except for those in areas immediately offshore, the fish are virtually all immature and consist of sockeye which have spent either one or two winters at sea.

In the Okhotsk Sea, sockeye are more abundant in July than in June, reflecting immigration to the area. They are, however, much less numerous than in the western Pacific. Little or no change in age composition has occurred since June. Immatures, while present, do not constitute an important element of the sockeye present.

During August, further changes occur in the distribution of sockeye salmon. The southern limit has shifted northward since May in association with warming of the surface waters from the south, as will be pointed out in Section XI. Sockeye salmon occur almost as far south as Latitude 48°N in the western Pacific and, in the eastern Pacific, as far south as about Latitude 52°N. In the northwest Pacific off Kamchatka, there are fewer sockeye in August than in July, but they are still nevertheless relatively numerous and consist almost entirely of immature fish. South of the Aleutian Islands, immatures are still very abundant and consist of much the same age groups as in July. South of the Alaska Peninsula and in the western Gulf of Alaska, immatures of 1- and 2-winter-ocean age constitute the sockeye population in August, but their numbers are lower than in July. Further

east, in the central and coastal Gulf of Alaska, sockeye are scarce. Only in the southeastern sector do maturing fish dominate in the catches.

In the Bering Sea, the distribution pattern in August is much like that in July.

VII. CHUM SALMON

A. Catch and Relative Abundance

1. *INPFC Research Vessel Operations*

Appendix Figure B-2 shows the relative abundance of chum salmon according to statistical areas and 10-day periods for the years 1955 through 1960, as determined from research vessel data. The abundance indices for the individual gillnet sets upon which these figures are based are given in Appendix Table C. The method of computing these indices was described in Section IV. The index used is the number of fish per 3,000 feet of gillnet, each mesh size equally represented.

The changes in relative abundance and distribution of chum salmon are considered below by the 10 major oceanic regions shown in Figure 1.

Okhotsk Sea.

Information on relative abundance of chum salmon in this region is limited to waters close to the Kuril Islands and off the southwest coast of Kamchatka in July of 1959 and 1960. In 1959, relative abundance levels ranged from low in southern areas to very high southwest of Kamchatka. In 1960, abundance levels were medium in all areas fished.

Landbased Fishery Region.

Only very little information is available on chum salmon in this region. During May and early June, chum salmon were present in varying numbers north of Latitude 42°N in offshore waters (1956), were abundant in some years (1955) in the northeast area and, in other years (1957), were abundant immediately east of the southern Kurils. Information on distribution and abundance levels after June is almost nonexistent.

Southeast Kamchatka-Southwest Aleutian.

Coverage in this region varied in extent and intensity annually. Waters southwest of the western Aleutians were fished throughout the season and those southeast of Kamchatka mainly during the period following mid-July. In 1958, the latter area was also fished during May and June, thus providing information on abundance levels for these waters during the early season.

Chum salmon were present in varying numbers throughout the Southeast Kamchatka-Southwest Aleutian region from May into September. During May, the area of maximal abundance usually was located south or southwest of Attu Island; the location varied in different years. In 1958, off Kamchatka, abundance levels ranged from low to medium. Highest levels were reported immediately south of Kamchatka. Through June in areas southwest of the Aleutians, abundance levels fluctuated, but in general were usually higher than in May (1956, 1957, 1960). In July, chum salmon abundance levels continued to vary between areas and usually were highest in waters approaching southeast Kamchatka (1956, 1957). This pattern continued into August, but abundance levels generally were lower. In 1955, during mid-September south of Attu (area E 7048), chum salmon were present in high levels of abundance.

Aleutian Region.

Like the Southeast Kamchatka-Southwest Aleutian region, this region was fished extensively throughout most of the season in all years.

The distribution and relative abundance of chum salmon varied seasonally and annually. During May and early June, abundance levels in most years increased offshore, indicating that the areas of concentration were considerably south of the Aleutians. This is particularly apparent in 1956, 1958 and 1960, south of Adak Island. In 1956, the southern limit was located between Latitudes 42°N and 40°N. Through June, abundance levels in the different areas fluctuated, occasionally violently, being either higher or lower than in May. These fluctuations presumably were caused by chum salmon movements. In July, chum salmon were more numerous in waters adjacent to the Aleutians than farther south. Their numbers declined somewhat in August. Fishing in August and September in 1955 and 1956 indicated that the southern limit of chum salmon was between Latitudes 47°N and 45°N.

Western Bering Sea.

Information on abundance and distribution is based on scattered sampling in 1958, 1959 and 1960. During May and early June, abundance levels throughout the whole region were very low, but tended to increase through this period, and offshore. In 1958 and 1959, in area E7056 in the eastern part of the region, abundance levels in late June were very high. In July, in most years, abundance levels were very high, indicating a rapid increase in the numbers of chum

almon since June. Maximal levels of abundance occurred in areas contiguous to northeast Kamchatka. During August, chum salmon continued to be very abundant, particularly in northern waters in 1958 and 1959.

Central Bering Sea.

Sampling in this region was reasonably intensive. Most of the fishing took place in waters south of Latitude 58°N, and during May through July.

The seasonal distribution pattern was rather similar for each year. During May, immediately north of the Aleutian Islands, chum salmon were present in relatively low numbers. Through June, their numbers increased. Usually, moderate levels of abundance were recorded, but occasionally very high levels also were reached. Chum salmon in 1959 were moderately abundant as far north as fishing was conducted, namely Latitude 60°N. Abundance indices for July indicated, in general, further increases since June, but some regional variations in abundance levels were evident. In general, chum salmon were more abundant westward and northward. In late July 1955, in area 8060, the relative abundance of chum salmon (CPUE, 213), as determined from a single set, exceeded by far any level encountered in any area at any time during the six years of research. Information on distribution in August is very limited. Fishing during this month showed that abundance levels were lower than in July, ranging between low and high.

Eastern Bering Sea.

Except for June, sampling annually in this area in other months was rather irregular. No fishing was done in May.

Fishing in June, mainly in the western areas, indicated that chum salmon were usually present in low to medium numbers. Their numbers tended to increase southward. In 1956, abundance levels were higher than in any year of sampling, ranging from low in central waters to very high in eastern waters. Through July and August, chum salmon progressively declined in numbers. By September, according to catches in 1956, they were virtually absent in the eastern part of the region.

Western Gulf of Alaska.

Coverage of the region has varied annually. In 1956, fishing extended as far south as Latitude 46°N. Usually, however, waters north of Latitude 50°N were fished. Except in 1959, when research vessels were present from late April through July, information is mainly for the period mid-July into September.

During late April, in the northern part of the region near Kodiak Island (1959) and throughout the whole region in May and June, abundance levels were low. In 1959, however, through June, abundance levels were higher than in other years, ranging from low to moderate. High abundance values occurred in waters just north of Latitude 50°N. During July and August, abundance levels varied with time and area, but in general they were very high, indicating an increase from June. Chum salmon were relatively more numerous in the northern and western parts of the region.

Central Gulf of Alaska.

Fishing in this region has been sparse in each year except 1956. During May and June, in most years, chum salmon were present in very low numbers in all areas fished. In 1957, medium abundance levels occurred in the central areas. In 1956, through July and August, abundance levels ranged from low to very high. Through this period the areas of maximal density shifted from the southeast to the northwest part of the region. In September, no chum salmon were caught in the southeastern part of the region, indicating that individuals susceptible to capture by surface gillnets were no longer present in these waters.

Coastal Gulf of Alaska.

Fishing locations within this region, which included waters north of Latitude 58°N and east of Longitude 135°W as far south as the Columbia River, ranged from about 50 to more than 400 miles offshore. Because of the varying proximity of different fishing stations to the North American coast, and the presence of several stocks having different spawning times, migration routes and destinations, the distribution pattern within these waters was extremely variable. This is indicated by the catches for earlier years.

The areas fished in May and June extended from the northern Gulf of Alaska south to about Latitude 44°N (1957). Chum salmon in different years were usually present in relatively low numbers throughout the region north of about Latitude 48°N. An exception to this general feature occurred in 1957 off the Queen Charlotte Islands when, during mid-June, a large number of chum salmon, predominantly maturing, was caught. In the northern areas in 1956, chum salmon were very abundant in mid-July, but declined to moderate levels by early August. In 1957, in the same area, very high abundance levels were recorded in late August. Fishing in several years during August indicated that chum salmon were virtually absent south of Latitude 52°N.

2. *Mothership Operations*

(a) Catch.

The reported annual catch of chum salmon by the Japanese mothership fishery during the years 1952 through 1960 in the North Pacific, the Bering Sea and the Okhotsk Sea, by month, is given in Table 24.

The sizes of the catches, according to statistical areas and intervals of five degrees of longitude, are shown in Appendix Figure C-2 by 10-day period. This figure is based on data given in Appendix Table D. While fishing effort played an important role in determining the size of catches, the figure shows seasonal and annual changes in the locations of the more productive areas in these regions, and hence areas of concentration.

North Pacific. The major portion of all chum salmon caught by mothership operations was taken in the North Pacific. Even in years when the fleets operated in the Okhotsk Sea and Bering Sea, between 63% (1956 and 1960) and 91% (1958) of the annual chum salmon catch was made in this region.

The annual catches varied considerably. From 1952 through 1955, catches rose steadily from 0.6 million to 15.5 million chum salmon. Catches during this period reflected not only the growth of the mothership operations but also the rather relatively high abundance levels of chum salmon. Thereafter, the annual catch fluctuated in response to changes in the relative importance and availability of chum salmon in relation to sockeye and pink salmon, particularly the former species, and to provisions resulting from the Japan-Soviet fishery treaty. The decline in 1956, a year when the effort was just slightly less than maximal, was principally due to exclusion of operations from waters west of Longitude 170°E prior to mid-July, a time and area which, in the past, had yielded a substantial proportion of the total catch. Diversion in that year of some effort into the Bering Sea for the first time presumably also accounted for part of the decline. A further marked drop in catch in 1957 was due to a shorter fishing season than usual, fishing having terminated in late July, and to a decline in the availability of the species. The catch in 1958 rose sharply to a maximum of 17.2 million chum salmon. This high catch was due to a generally high abundance level of the species and, excluding fishing activities in the Okhotsk Sea, a consolidation of fishing effort in the North Pacific. Following 1958, shorter seasons and withdrawal of some effort from the area caused catches to fall sharply. The catch in 1960 amounted to 6.7 million fish, the lowest since 1953.

The important month for chum salmon catches has varied, depending upon the commencement and duration of the mothership operations. Through the years, June has produced a greater part of the catch than any other month, averaging 44%. In 1956 and 1957, the size of the catches in May and June were about equal.

In May, even though the fishing areas varied annually to some extent, chum salmon were caught generally between Longitudes 155°E and 180° and Latitudes 46°N to 54°N. The bulk of the catches was made between Longitudes 165°E and 175°E and Latitudes 48°N and 52°N. In 1956 and 1959, the area of good catches extended southward to include area E6546. In 1957, in contrast to most years, the catch was distributed over a much wider area. The areas of best catch were located north of Latitude 50°N rather than south of this meridian.

During June, the catches increased with each succeeding 10-day period and generally exceeded those for other months. The areas of maximal catch, however, were either unchanged from May or were located to the north and west. The highest catches occurred between Longitudes 160°E and 170°E.

Table 24. Chum salmon catches (in thousands of fish) by Japanese mothership operations, 1952–1960.

	North Pacific					Bering Sea					Okhotsk Sea					
Year	May	June	July	Aug.	Total	May	June	July	Aug.	Total	May	June	July	Aug.	Total	Total
1952	124	311	192	2	629	—	—	—	—	—	—	—	—	—	—	629
1953	261	1,377	982	92	2,712	—	—	—	—	—	—	—	—	—	—	2,712
1954	902	3,782	3,835	837	9,356	—	—	—	—	—	—	—	—	—	—	9,356
1955	3,485	7,228	3,036	1,800	15,549	—	—	—	—	—	—	1,485	1,310	166	2,961	18,510
1956	4,484	4,765	1,786	1,212	12,247	—	1,428	2,423	—	3,851	—	1,037	2,144	44	3,225	19,323
1957	3,854	3,554	1,053	—	8,461	—	620	177	—	797	—	1,565	1,096	—	2,661	11,919
1958	3,124	6,051	5,773	2,220	17,168	—	—	—	—	—	—	953	585	84	1,622	18,790
1959	3,229	6,477	1,793	—	11,499	—	48	1,309	—	1,357	—	—	—	—	—	12,856
1960	1,050	2,177	3,384	88	6,701	—	3,019	801	—	3,820	—	—	—	—	—	10,521

During July, motherships operated mainly between latitudes 46°N and 54°N and west of Longitude 170°E. In the main, largest catches were made between Longitudes 160°E and 165°E and between latitudes 48°N and 52°N.

Catches declined during August as the fishery approached termination, the time of which varied in different years. Largest catches were usually made south and southeast of Kamchatka. In 1958, moderately good catches, exceeding those in July, were made as far east as waters south of Attu Island in the western Aleutians.

Bering Sea. Fishing in this region usually began in mid-June and ended in mid-July. Chum salmon catches ranged from 0.8 million (1957) to 3.8 million (1956 and 1960). The areas of catch, in contrast to those in the North Pacific and the Okhotsk Sea, did not follow a consistent annual geographic pattern, but rather have varied in location.

Considering the years of good catches separately, in 1956, the fishery began in mid-June in waters immediately north of the western Aleutian Islands, mainly between Longitudes 175°E and 180°. Catches amounted to slightly more than 500,000 fish. By July, the fleet had divided into two parts, one part advancing into waters between Longitudes 180° and 175°W and northward to Latitude 60°N, the other part moving into waters of the northwest Bering Sea, principally into areas E6558 and E7058. In each sector the catch was more than one million fish, that in the latter sector being slightly larger. In 1959, the fishery operated mainly in the Bering Sea west of Longitude 175°E. The area of maximal catch was E7056. Also, for the first time, waters north of Latitude 60°N were fished (area E7560). The catch was small, amounting to 34,000 fish. In 1960, the fishery was widely scattered, but occurred mainly between Longitudes 180° and 175°W and as far north as Latitude 60°N. The catch in these waters amounted to 2.7 million fish, or 72% of the total Bering Sea catch. Area 8058 produced the largest catch of any single statistical area, almost one million fish.

Okhotsk Sea. Commercial operations in the Okhotsk Sea took place only during 1955 to 1958, inclusive, and mainly during June and July. Because of relatively little effort, catches were considerably smaller than those made in the North Pacific and were about equal in size to those made in the Bering Sea, ranging from a maximum of 3.2 million chum salmon in 1956 to a minimum of 1.6 million in 1958. The decline from 2.7 million fish to 1.6 million from 1957 to 1958 can be explained by the reduction in fishing effort from two mothership fleets to one in the respective years and by successively shorter seasons. In years when the fishery operated in more than one area, area E5050 consistently yielded the largest catches.

TABLE 25. Annual chum salmon catch per tan values in mothership operations, by major fishing region.

Year	North Pacific	Bering Sea	Okhotsk Sea
1952	1.1	—	—
1953	2.1	—	—
1954	2.8	—	—
1955	2.3	—	4.2
1956	1.5	2.9	6.9
1957	1.5	0.7	4.9
1958	2.0	—	4.1
1959	2.0	1.1	—
1960	1.4	2.2	—

(b) Relative Abundance.

The annual catch per tan (180 feet) of chum salmon from 1952 to 1960 in each major region is listed in Table 25. These data are treated in greater detail in Appendix Figure D-2, which shows the indices of abundance by statistical area and 10-day period, thus revealing monthly changes in relative abundance and distribution. These detailed indices were computed from catch and effort data given in Appendix Table D. Although fishing patterns have varied to some extent annually, the data nevertheless reveal the presence of a basic annual distribution pattern.

North Pacific. The relative abundance of chum salmon varied annually during 1952 to 1960. During 1952 to 1954, abundance levels increased. From 1954, when the fishery had reached considerable size and exploited a vast area, to 1957, abundance indices dropped from a high of 2.8 fish per tan to 1.5 fish per tan. Relative abundance levels had increased somewhat in 1958 and 1959 (2.0 fish per tan), but by 1960 had again dropped to levels (1.4 fish per tan) recorded for the low years of 1956 and 1957.

In 1952 and 1953, fishing in May indicated that chum salmon were relatively most abundant in waters immediately south of the western Aleutians. In 1953, abundance levels were higher to the westward and northward in June. Levels appeared to decline through July.

In 1954, in May, south of the western Aleutians, chum salmon were somewhat uniformly distributed. There was a suggestion that abundance levels increased slightly northward. During June, in the area bounded

by Longitudes 160°E and 175°E and Latitudes 48°N and 54°N, abundance levels were highest in the waters adjacent to Attu Island. To the south and west, abundance levels for similar periods were lower. In July, chum salmon were most abundant southeast and south of Kamchatka, with highest levels occurring usually in southern waters during early July. Thereafter, abundance levels declined. In August, especially southeast of Kamchatka, during the latter part of the month, chum salmon showed slight increases in abundance. One possible explanation for this late-season rise in abundance levels is the arrival of later-migrating chum salmon in the area.

In 1955, fishing in May between Longitudes 165°E and 180° showed that chum salmon were present generally, but that their numbers increased from south to north. This was apparent also in June further west. Chum salmon were particularly abundant in area E6050 in mid-June. In July, two centers of abundance occurred, one in area E6048 during early July, the other in area E6052 during late July. In August, off Kamchatka, abundance levels were lower than in July, but increased offshore.

Research vessels fishing with large quantities of commercial gillnets along Latitude 48°N and east of the mothership area in May and June indicated that chum salmon were less abundant there than in the mothership area and that their numbers increased northward toward the Aleutians.

Information on monthly changes in relative abundance in 1956 mainly pertains to waters east of Longitude 170°E, because of fishery regulations in that year. Chum salmon were most abundant in May and declined with each successive month into August. An exception to this trend was noted for waters near Attu in August, where chum salmon increased in numbers. In July, considering the whole region, abundance levels were highest in areas immediately off Kamchatka and declined eastward. Throughout the season, abundance levels increased from south to north.

In 1957, fishing began in early May and was carried out further to the west than in any previous year. Abundance levels varied between areas, but two areas of concentration were suggested; one south of Kamchatka, the other southwest of Attu. Generally, abundance levels in early June were slightly higher than in May but declined thereafter. As in other years, chum salmon increased in abundance northward through the region fished.

In 1958, abundance levels fluctuated only slightly throughout the season. Indices for the period from late May into mid-June showed somewhat greater numbers of chum salmon southwest of the Aleutians and southeast of Kamchatka, thus resembling 1957, with peak abundance levels occurring in mid-June. Generally, chum salmon were somewhat more abundant in August than in July, particularly in waters south of Attu Island.

In 1959, chum salmon in early June were most abundant in area E6048 and southwest of the Aleutian Islands. Maximal densities in mid-June were located in areas E6050 and E7052, indicating a northerly shift in the areas of abundance. During late June and into July, particularly in the Attu Island area, abundance levels declined. However, southeast of Kamchatka in area E6048 abundance levels were again quite high in mid-July.

In 1960, in late May, waters mainly between Longitudes 165°E and 175°E and Latitudes 48°N and 54°N were fished. Chum salmon densities increased to the northwest, the highest level occurring in area E6554. Fishing in early June throughout the North Pacific again indicated that the largest concentrations were located southeast of Kamchatka and in waters close to the western Aleutians. In July, chum salmon were relatively most abundant in area E6052. Their numbers declined to the south and east from this area.

Bering Sea. Information on distribution and relative abundance levels of chum salmon in the Bering Sea is based on mothership operations in 1956, 1957, 1959 and 1960. As in the North Pacific, chum salmon varied considerably in their abundance each year. The annual catch per tan indices for the successive years are 2.9, 0.7, 1.1 and 2.2, respectively (Table 25). Supplementary information on distribution and relative abundance is also available for 1955 and 1958 from research vessels fishing with commercial gear.

In 1955, according to catches by commercial gear fished by research vessels, the most prominent feature regarding the distribution of chum salmon was their relatively high level of abundance in the northern areas of the Bering Sea, particularly in areas E7060 and E7560 during early August, and their decline to the south and east.

In 1956, north of the Aleutians during mid-June, chum salmon were particularly abundant. Abundance levels were higher here than in any region in the North Pacific. During July, both in the Central and Western Bering Sea regions, chum salmon were

also very abundant, particularly in the former region. Their relative numbers increased from south to north. Highest density levels occurred in area E8056.

Chum salmon were much less abundant in 1957 than in 1956, but the distribution pattern appeared similar in the two years.

In 1958, according to catches by research vessels fishing with commercial gear, chum salmon were not particularly abundant. An exception to this general feature was area E7056 where, in June, only chum salmon were relatively numerous.

In 1959 in July, when fishing was reasonably extensive, chum salmon were most abundant in area E6558.

In 1960, chum salmon were relatively more abundant in the Central than in the Western Bering Sea region during the latter part of June and early July.

Okhotsk Sea. Relative abundance indices were considerably higher in the Okhotsk Sea than in either the North Pacific or the Bering Sea during 1955 through 1958. Annual catch per tan indices ranged from 4.1 (1955 and 1958) to 6.9 fish (1956) (Table 25). In the areas fished, peak density levels were reached earlier in the southern areas than in the northern areas, indicating a northward shift in the concentration of chum salmon through the fishing period. In 1957, density levels fluctuated through the season, suggesting the presence of two groups of chum salmon with slightly different migration times.

3. *Landbased Region Operations*

Information on relative abundance and distribution of chum salmon in the landbased fishery region was obtained from catch data provided by Japanese fishing training vessels using commercial gillnets (4.5″ mesh) permissible for that region in the years 1956 through 1960. This is the best source of data available and is considered reasonably representative of events in the region and certainly more reliable than catch and effort data for commercial landbased operations. Because the gillnets officially permitted in the landbased fishery are smaller in mesh size than those fished by motherships (4.8″), abundance indices for the two major commercial areas are not directly comparable.

In May, chum salmon were caught throughout the region east of the Kuril Islands and Hokkaido and as far south as about Latitude 40°N. In 1956, chum salmon were extremely abundant east of the southern Kurils (area E5044) and their numbers decreased offshore. In June, according to fishing in 1958 and 1960, abundance levels fluctuated, but in general tended to be higher than in May. Areas of peak abundance were located off the southern and central Kuril Islands. Relative abundance levels in July in each year were lower than in June, suggesting that the bulk of the chum salmon had passed through the area. Fishing during late July and early August 1960 in area E4542 failed to catch any chum salmon. In area E6046, to the northeast, in late July of 1959 and 1960, chum salmon were relatively numerous.

4. *Summary*

A consideration of catch and CPUE data for both research and commercial operations on a regional basis from May into August has shown that a consistent basic annual distribution pattern existed. This was very apparent for regions where sampling was extensive in several years. Presumably this would apply to regions where sampling was less adequate.

Changes in the relative abundance of chum salmon, as indicated by Japanese high seas fishing and research vessel operations in the North Pacific and adjacent seas, mainly from May through August, are illustrated schematically in Figure 18. The same restrictions and qualifications stated for sockeye salmon apply to chum salmon.

Mothership chum salmon catches in the North Pacific, by virtue of a more intense fishery, exceeded by far those made in the Bering Sea and in the Okhotsk Sea. In years when fleets operated in each region, the North Pacific accounted for at least 63% of the total chum salmon catch. In 1958, the year of highest catch, 17.2 million chum salmon were caught in the North Pacific.

In the North Pacific, catches were usually largest in June, next largest in July. May and August catches were considerably smaller; the size of the catches in these months depended largely on starting and closure dates for the fishery, which varied annually. In later years, catches in May and August were relatively small, as fishing started later and ended earlier.

In April, chum salmon were relatively low in numbers south of Kodiak Island in the Gulf of Alaska (1959). Fishing was not undertaken elsewhere.

In May, chum salmon were caught throughout the North Pacific. The southern limit in the western Pacific was about Latitude 40°N and in the eastern Pacific about Latitude 46°N.

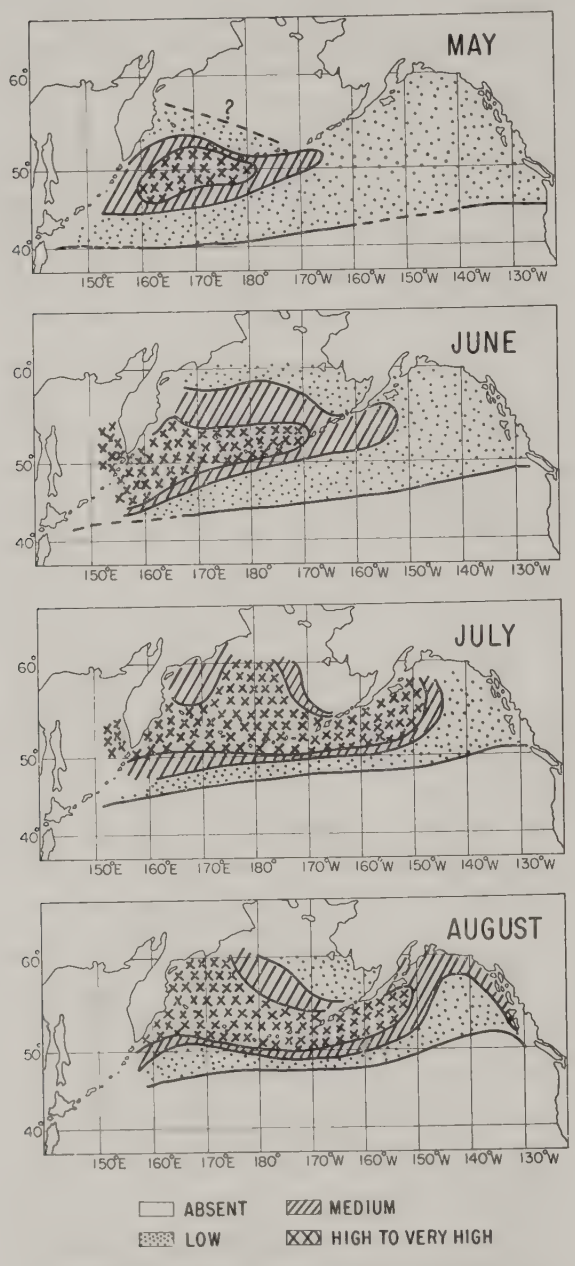

FIGURE 18. Schematic diagram showing distribution and relative abundance of chum salmon, May through August, maturing and immature fish combined.

Largest catches in May by the mothership fishery were made between Longitudes 165°E and 175°E and Latitudes 48°N and 52°N. Within these waters, catches usually were larger north than south of Latitude 50°N. In 1957, good catches were made over a wider area than in most years.

Research and training vessels operating in the land-based region in May indicated, in some years, that chum salmon occurred in large numbers off northern Japan and the southern Kuril Islands and tended to decrease eastward. Mothership and INPFC research vessel operations further north and east showed that chum salmon increased in numbers from south to north and that the major concentration was located south and southwest of the western Aleutian Islands. In some years (1957 and 1958), chum salmon were also found to be numerous south and southeast of Kamchatka. Information for other areas of the North Pacific is rather meager, but chum salmon would appear to be relatively low in numbers.

In the Bering Sea in May, chum salmon were caught in low numbers as far north as fishing by research vessels was carried out (Latitude 55°N). Therefore, their absolute northern limit is not known. In all probability they occurred further north, at least in some areas. This is suggested by research vessel catches in 1958. In that year, chum salmon were caught in early June in small numbers in the northwest area of the Bering Sea (area E5558).

Information on the occurrence of chum salmon in the Okhotsk Sea in May is lacking. Presumably, chum salmon were present at least in southern waters since the species occurred immediately south of Kamchatka in May and in the Okhotsk Sea in relatively high numbers in early June.

In June, in the North Pacific, chum salmon were present in varying numbers throughout the region. Mothership catches increased with each succeeding 10-day period and were largest between Longitudes 160°E and 170°E.

In the western Pacific, according to both research and commercial operations, relative abundance levels in June fluctuated with time and area, suggesting that chum salmon were actively migrating (1956, 1957 and 1958). Chum salmon were not particularly abundant immediately off Kamchatka, but their numbers increased eastward, becoming very high in areas adjacent to the western and central Aleutian Islands. Further south of the Aleutians their numbers declined. Further eastward and into the western Gulf of Alaska, chum salmon were more abundant in June than in May, but not as numerous as in the Aleutian region. Abundance levels were higher offshore than closer to land (1955, 1959). In the Gulf of Alaska, in most years, chum salmon were not particularly abundant.

In the Bering Sea, chum salmon occurred generally in June and abundance levels varied between areas and years. Abundance levels were usually highest in the south Central Bering Sea region and declined from these waters. In the Eastern Bering Sea region, abundance levels were usually low in all years but 1956, when they ranged from low to very high.

In the Okhotsk Sea, southwest of Kamchatka, according to mothership operations, relative abundance levels in June were considerably higher than in either the North Pacific or the Bering Sea. Abundance levels were maximal during the early part of the month and declined steadily thereafter. Research vessels operating in southern waters (1959) showed that chum salmon increased in abundance northward.

In July, the important area for mothership catches was located between Longitudes 160°E and 165°E and between Latitudes 48°N and 52°N.

In the North Pacific, according to both commercial and research vessels, the relative numbers of chum salmon in July varied within and between areas, as noted for June, indicating that the species was actively migrating. Abundance levels were low to moderate east of the Kuril Islands. Further north, in waters southeast of Kamchatka, they were considerably higher, indicating that chum salmon were much more numerous. Eastward and immediately south of the Aleutians, relative abundance levels fluctuated but remained rather high. In 1958 and 1959, chum salmon were abundant in the Attu area, suggesting another center of concentration. In more southern waters they were present in lower numbers. In the Gulf of Alaska, they were more numerous in July than in June. Highest levels of abundance occurred in the western and central areas of the region. Chum salmon would appear to be absent in surface waters in the southeast areas of the Gulf of Alaska by late July.

In the Bering Sea, chum salmon were present in July throughout the region at least as far north as about Latitude 60°N. Their numbers were highest in the central areas, lower to the westward and lowest to the eastward.

In the Okhotsk Sea, through July, relative abundance levels declined from June, but were still higher than in the two other regions. Chum salmon increased in numbers northward.

During August, commercial catches, and relative abundance indices for both mothership and research vessel operations in the western Pacific, indicated that chum salmon were less abundant than in July. They were most numerous south and southeast, mainly, of Kamchatka. In 1956 and 1958, however, according to commercial operations, chum salmon were most abundant southwest of the western Aleutians. Research vessels operating in August south of the Aleutians and the Alaska Peninsula and in the western areas of the Gulf of Alaska revealed that abundance levels of chum salmon were usually high. Elsewhere, except in immediate coastal areas, chum salmon were not particularly abundant.

The southern limit of chum salmon distribution shifted progressively northward with each succeeding month from May. By August, chum salmon were caught as far south as about Latitude 44°N in the western Pacific and about Latitude 52°N in the eastern Pacific.

Limited fishing by research vessels in August in the Bering Sea suggested that chum salmon were present throughout the region. They were most abundant in the northwestern areas and declined eastward and southward from this sector.

Information on the relative numbers in the Okhotsk Sea after July is lacking, but presumably chum salmon were still present.

B. Distribution of Immature and Maturing Chum Salmon

1. *INPFC Research Vessel Operations*

Information on the distribution of immature and maturing chum salmon is available for 1956 to 1960. The information for each year has varied in its completeness. In 1956, information was mainly for the eastern Bering Sea and the eastern North Pacific; in 1957 and 1959, for virtually all areas fished by research vessels; in 1958, for the central and eastern regions only.

The method of separating immature and maturing fish in research vessel samples has already been referred to in Section IV. The percentage estimates of immature chum salmon in the various samples are shown by statistical areas and 10-day periods by numerical values directly above the relative abundance symbols in Appendix Figure B-2. The values are based only on samples of 10 or more fish. The monthly and annual changes in the relative importance of immature and maturing chum salmon are considered by region.

Okhotsk Sea.

The proportion of immature individuals in this region is known only from catches made in July 1959.

In the southern part of the region during the early part of the month, only mature individuals were caught. In mid-July, immatures were absent in southern waters but increased in importance northward into area E5050. In this area, their importance also increased from mid to late July.

Southeast Kamchatka-Southwest Aleutian.

In May and early June in waters south and southwest of Attu Island, the percentage of immatures in the different samples ranged from 0% to 50%. The proportion of immature chum salmon in general increased southward. Information on maturity of chum salmon in waters off Kamchatka during this period is lacking, but if immature fish were present it would appear that their numbers would be few. In July, according to sampling in 1957, the proportion of immatures throughout the region was very much higher than in June, usually forming over 80% of the fish present. In August 1959, immatures were more numerous offshore than close to Kamchatka.

Aleutian Region.

South of the Aleutians, the relative importance of immature and maturing chum salmon varied by area. In May in 1957, the percentage of immatures was higher in samples from the eastern areas than in samples from the western areas, while in 1959 the trend was reversed. In general, the percentage of immatures tended to increase southward. Percentage values for immatures for all areas ranged from 0% to 48%, indicating that maturing fish were more numerous than immatures. During June, the percentage of immatures in all areas increased rapidly and markedly. The percentage in late June ranged from 78% to 96%. Highest values were from catches close to the Aleutians. Presumably, this rapid change in the relative importance of the two groups was due to the emigration of maturing fish from the area and the northward movement of immature individuals. After mid-July, immature fish in most years virtually comprised the entire population. In September in 1956, south of Adak Island, their percentage was reduced, ranging between 66% and 77%.

Western Bering Sea.

Information on the relative importance of immature and maturing chum salmon in this region is mainly available from catches made in 1959. During June, limited fishing in the southeastern sector showed that fish there were mainly maturing. This was also indicated by sampling in 1958 in May and early June. In late July and August in the western and northern areas, immatures formed a very high proportion of the catch. The percentages varied between areas, and ranged from 51% to 100%. Percentage values of 80% or higher occurred in more than one-half of the samples.

Central Bering Sea.

Extensive sampling in several years throughout most of the entire period from late May into August has provided much information on the relative importance of maturing and immature chum salmon in this region.

A single sample in May 1958, in area 8052 immediately north of the Aleutians, contained maturing fish only. Through June in all years, the percentage of immatures increased greatly, but considerable variation in the proportions of immature and maturing individuals occurred between areas. For example, in 1957, in area 8052, the percentage of immatures increased from 61% to 95%. In area E7552, immediately to the west, the percentage of immatures decreased from 86% in early June to 66% in mid-June. These changes in the relative importance of immature and maturing chum salmon were somewhat similar to those noted for the Aleutian region, and presumably were also due to the migrations of maturing and immature fish. In 1959, when information on the changing proportions of the two groups in June in this region was best, the percentage of immatures ranged from 0% to 73%. Considering the region as a whole, the percentage of immatures decreased northward. North of Latitude 58°N, immatures amounted to 32% of the samples. In all years for which there are data for July and August, the percentage of immatures ranged from 50% to 100%. Southern catches consisted almost entirely of immature fish. Percentages of immatures in samples from northern areas were slightly lower, thus continuing the trend observed in June.

Eastern Bering Sea.

Information on the relative importance of maturing and immature chum salmon in this region is primarily based on catches made during June. Considering data for all years, immature fish were present mainly in the western and southern parts of the region, where they constituted as much as 30% of the samples. Samples for late July 1957 and August 1956 suggested that at these times maturing chum salmon were scarce or absent in the high seas areas.

Western Gulf of Alaska.

Fishing in various years was carried out from late April into September. Samples collected during

late April from south of Kodiak Island and during May from the northern part of the region have shown chum salmon to be mainly maturing individuals. During June, extensive fishing showed immatures to be present in varying numbers and to increase in relative proportions southward. Along Latitude 50°N, they amounted to 80% or more of the chum salmon present. After mid-July, maturing fish formed only a small part of the catch and their proportion was highest in areas adjacent to the Alaska Peninsula and south of Kodiak Island. Further offshore, the catches consisted of immature fish only.

Central Gulf of Alaska.

Information on maturity of chum salmon in this region is based on rather extensive fishing from July through August in 1956 and on catches obtained at widely scattered stations in 1957, 1958 and 1959.

The relative importance and distribution of immature and maturing chum salmon in this region varied greatly.

In 1956, very small catches during May and early June south of Latitude 50°N suggested the presence of maturing fish only. By mid-July and continuing into September, immatures were virtually the only chum salmon present throughout most of the region. The pattern in 1957 was similar to 1956. In 1958, however, according to limited and scattered sampling in May, June and August, immatures were much less important than in the two previous years. In 1959, immatures were present in substantial numbers in southern areas in May.

Coastal Gulf of Alaska.

In this region through the season the proportion of immature and maturing chum salmon varied between areas. These variations were probably due to maturing individuals of various stocks with different migration times approaching their respective coastal areas. Except in 1957 in area W4558 in the north, where immatures amounted to more than 90% of the chum salmon present in July and August, the proportion of maturing fish tended to increase through the season.

Figure 19 schematically shows the distribution of immature and maturing fish in the North Pacific and the Bering Sea. The relative importance of immature fish in the various regions is contoured according to three percentage levels: 0%–20%, 21%–80% and 81%–100%. The contour line for each level was obtained by averaging the percentage values for immature individuals in each statistical area for all years (Appendix Figure B-2). Year to year variations in sampling, in stock size and the age at which chum salmon mature can influence the proportions of immature and maturing individuals, but since the data are based on information for several years, and show a consistent annual trend, in all probability anomalous conditions are minimized.

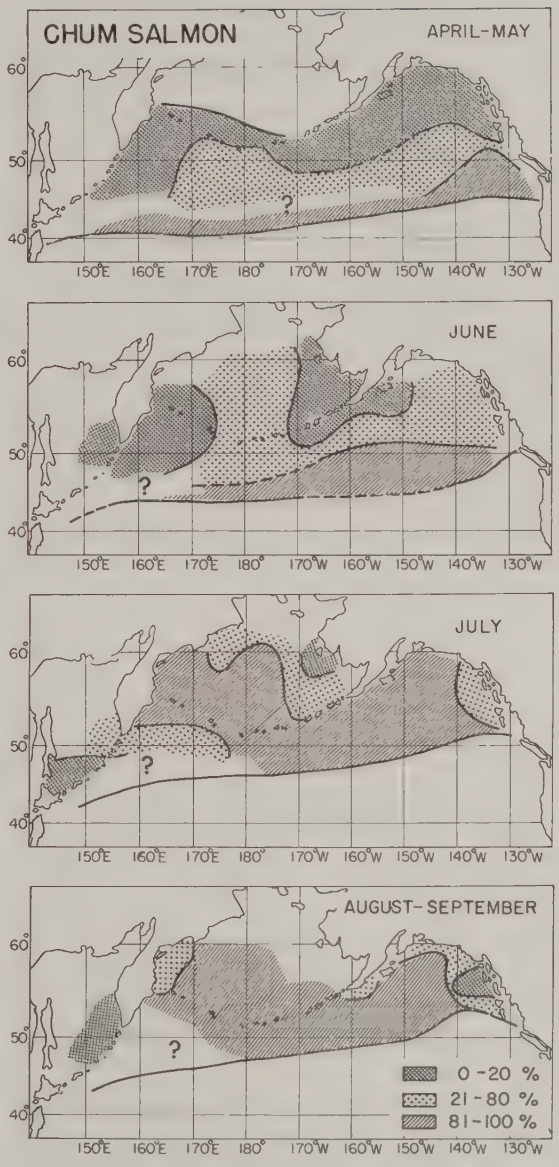

FIGURE 19. Schematic diagram showing the distribution of immature chum salmon in the North Pacific and adjacent seas, by month.

During April and May, primarily, immature individuals would appear to be absent in the western and northern areas where chum salmon were caught. They were present, however, in the central and eastern North Pacific. Their proportion in these waters increased southward and eastward. Since immatures, almost exclusively, were present in the southeastern Gulf of Alaska, it is presumed that they formed a very high percentage, if not all, of the chum salmon in waters some distance further west in the extreme southern range of the species. Through June, over a vast area, the proportion of immature fish increased markedly over May levels. Immatures now formed substantial proportions of the catches in most areas of the central and eastern North Pacific and in the central Bering Sea as well, thus indicating a northward movement into these regions. During July, immatures continued to increase in their relative importance and now formed a very high percentage of the catches generally, including the western Bering Sea. In coastal areas and in the Okhotsk Sea, immatures were not as important in the catches as further offshore. Offshore, the percentage of immatures increased northward. Considering all regions, this general pattern would be expected since maturing fish would be evacuating the high seas regions as they migrated shoreward. In August, a further expansion of the areas occupied by immatures occurred, and usually, especially on the high seas, all chum salmon were virtually immature. Occasionally, however, their relative numbers fluctuated, suggesting the presence of a late-migrating maturing stock. Only in immediate coastal areas did the proportion of immatures consistently tend to decrease.

2. *Mothership Operations*

Figure 20 shows the percentages of immature chum salmon in samples of mothership catches, by month, from May through August for the period 1957–1960, inclusive, and by four major regions, namely the Okhotsk Sea, waters west of Longitude 170°E, waters east of Longitude 170°E and north of Latitude 52°N, and waters east of Longitude 170°E and south of Latitude 52°N.

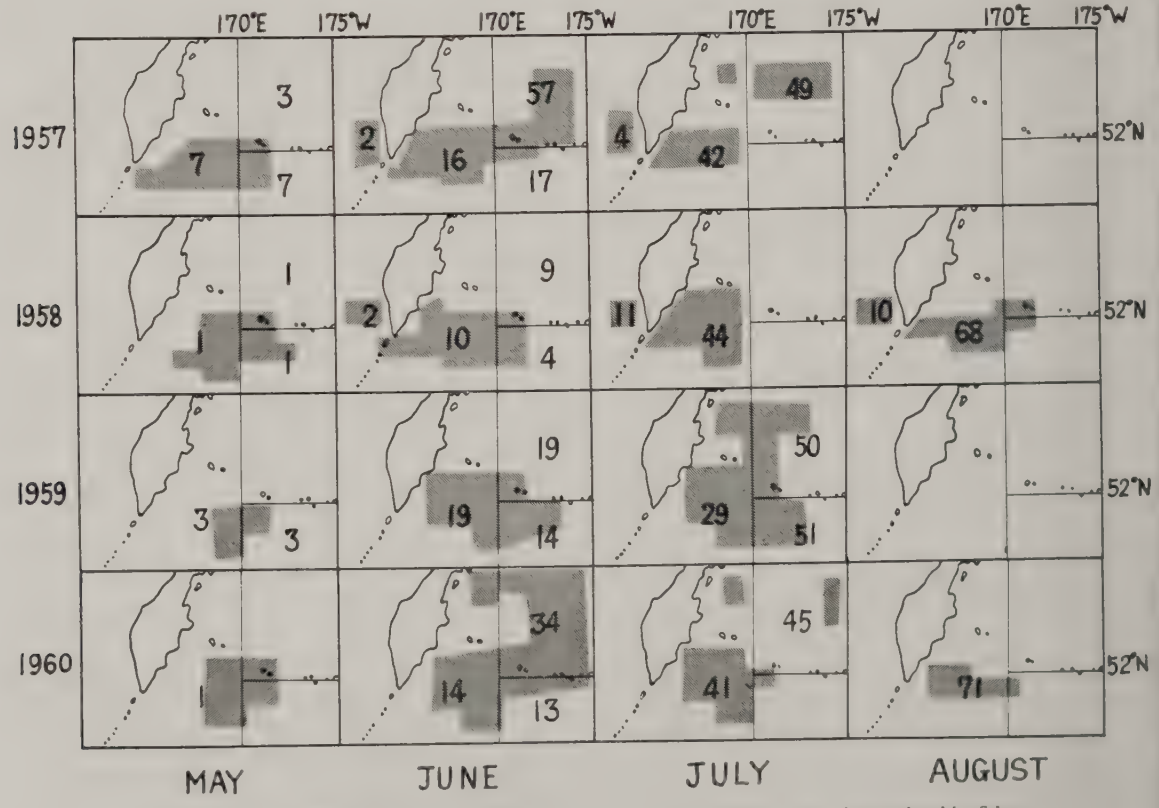

Figure 20. Percentage of immature individuals in chum salmon samples from the mothership fishery, 1957–1960. Shaded areas indicate fishing areas.

The actual numbers of fish examined in this study are not known, but since the samples providing information on age composition were also used in maturity studies, the numbers of fish examined in each year must have been large. The presumed origins of the samples, based on monthly disposition of the fleets, are illustrated by the hatched areas in Figure 20.

In each of these years, the changing pattern in the proportions of immature and maturing individuals was similar. May samples in each year, collected in the North Pacific, showed that chum salmon were mainly maturing fish. The percentage of immatures in the samples ranged from 1% to 7%. In 1957, east of Longitude 170°E, there was a suggestion that the proportion of immatures increased slightly southward.

In June in each region, the percentage of immatures in the samples increased considerably over values observed for May. In the North Pacific, the percentage of immatures in samples from west of Longitude 170°E was either equal to or larger than that of immatures in samples from east of that longitude. The extremely high values for the Bering Sea east of Longitude 170°E and north of Latitude 52°N in 1957 and 1960, 57% and 34%, respectively, are for waters mainly in the eastern part of the region.

In the Okhotsk Sea, immatures were considerably less numerous than in either the North Pacific or the Bering Sea, forming only 2% of the samples.

In July, in the region off Kamchatka east to Longitude 170°E, the percentage of immatures continued to increase above levels in June, amounting to slightly more than 40% in each year but 1959. In 1959, immatures formed 29% of the samples.

In the waters east of Longitude 170°E and north of Latitude 52°N in July, the percentage of immatures was higher than in waters west of Longitude 170°E, immatures forming between 45% and 50% of the samples. In 1957 in the former region, the percentage of immatures in July was lower than in June, while in 1959 and 1960, the percentages were considerably higher. The reversed trend in 1957 possibly can be explained by variations in the areas sampled in different years, or by annual variations in yearclass strengths, which in turn could be responsible for annual variations in the numbers of fish maturing in any one year. In waters east of Longitude 170°E and south of Latitude 52°N in 1959, immatures formed a considerably higher percentage of the samples in July than in June and were about as numerous as in samples from waters north of Latitude 52°N (almost 50%).

In the Okhotsk Sea, the percentage of immatures was slightly higher in July than in June (4% in 1957, 11% in 1958).

Information on the percentage of immature and maturing chum salmon in August is based on operations in 1958 and 1960 west of Longitude 170°E; in 1957 and 1959 fishing terminated before August. In the region east of Kamchatka, about 70% of the samples consisted of immatures, representing a further increase in the importance of this group since July. According to data for 1958, the percentage of immatures in the Okhotsk Sea during August was unchanged from July.

Thus, sampling of the mothership chum salmon catches from the North Pacific and the Bering Sea for maturing and immature individuals revealed that, during May, the samples from all regions consisted of maturing fish almost exclusively. The proportion of immatures increased as the season advanced, and eastward from Kamchatka. By August, more than 50% of the chum salmon in the samples from catches east of Longitude 170°E were immature individuals. In the Okhotsk Sea, immature fish formed a much smaller percentage of the samples than they did in the North Pacific and the Bering Sea during the same month. In the Okhotsk Sea, the proportion of immature fish increased from 2% in June to 10% in August.

3. *Landbased Region Operations*

Information on maturity of chum salmon, based on gonad sampling, is lacking for this region. Age data (Figure 25) indicate a probable increase in the proportion of immatures after June since the percentage of 3-year-olds is usually highest during July and August (chum salmon usually spawn as 4-year-olds).

4. *Summary*

Maturity studies using gonad weights and body weights of chum salmon have provided information on the distribution and proportions of immature and maturing individuals in the North Pacific, the Bering Sea and Okhotsk Sea. Samples of catches by both research vessel and mothership operations have been used in this study. Some information for the landbased region was obtained by considering age composition data from catches made by Japanese research and training vessels.

Chum salmon south of Kodiak Island in late April, according to research vessel samples in 1959, were maturing individuals.

In May, information is mainly available for the

North Pacific. Chum salmon in waters close to the continents and adjacent major islands were mainly maturing individuals. Further offshore and to the south the proportion of immatures increased. South of the central Aleutian Islands, immatures comprised about one-half of the samples. Research vessel catches indicated immatures to be more numerous than did mothership operations, especially in 1959. The differences in the percentage values of immatures is explained by selectivity of gillnets used in the respective operations. In the southern areas of the Bering Sea, maturing individuals only were caught. Information is lacking for the Okhotsk Sea.

In June, throughout the North Pacific and the Bering Sea, the proportions of immatures increased markedly and rapidly over May levels. This increase was shown by both research vessels in all years and by mothership operations in most years, in areas of mutual operation. Research vessels indicated that the percentage of immatures varied between areas and years but usually immatures were relatively more important in the southern areas of the Bering Sea and in waters south of the central Aleutians eastward including the Western Gulf of Alaska region. In late June, immatures usually formed a very high percentage of the catches. In the northwest Pacific areas and Gulf of Alaska, immatures increased southward. In the Coastal Gulf of Alaska region, considerable variation occurred in the proportions of maturing and immature chum salmon.

In the Bering Sea, the proportion of immatures was highest in the central areas and to the south, and decreased shoreward. In the northern areas in 1959, immatures formed about one-third of the chum salmon caught.

In the Okhotsk Sea areas fished by motherships, the percentage of immatures was very low.

During July and through August into September, according to both research and commercial samples, the percentage of immature chum salmon increased generally. In the coastal areas, immatures were proportionately less important than on the high seas, but still formed the bulk of the fish present in most areas. Exceptions were noted, however, in the Coastal Gulf of Alaska region where maturing fish usually predominated. In almost all of the high seas areas, immatures usually formed 90% or more of the samples. Frequently, immatures only were present. Occasionally, however, lower percentage values were recorded which presumably reflected the occurrence of late-migrating maturing individuals.

In the Okhotsk Sea, according to mothership operations, about 10% of the chum salmon caught was immature.

C. Distribution of Chum Salmon by Age

1. *INPFC Research Vessel Operations*

Chum salmon caught by research vessels included fish which had spent from one to five winters at sea (2nd to 6th year). The catch of each age group expressed as a weighted value for 3,000 feet of INPFC gillnet is given in Table 26 by month and statistical area for the years 1956 through 1960. These values are grouped into the same categories used in the study of the relative abundance of the species. Therefore, indices of 1–10 are considered low; 11–20, medium; 21–30, high; over 30, very high. Information for 1956 and 1958 is based on catches made by United States and Canadian research vessels only.

The table shows the weighted number of chum salmon of each age in all catches regardless of sample size. However, when considering the data, catches larger than 25 fish were mainly considered. In a few instances, very large catches were sub-sampled and accordingly abundance indices for each age are for partial catches. In these cases, the different ages are presumably represented in their approximate proportion but the relative abundance of each age group would be low.

In May, information on the distribution and relative importance of the different age groups is available mainly for areas south of the Aleutians, where sampling locations varied between years, and for the eastern part of the Gulf of Alaska. South of the Aleutians, fish from two to six years of age (one to five winter checks) were present. Four-year-old fish usually dominated, occurring in relatively low numbers in catches from most areas in each year except 1959, when they appeared in medium to high levels. In the eastern areas of the Gulf of Alaska, chum salmon of ages two to five years were present, but were less numerous than south of the Aleutians. In contrast, however, 3-year-old fish dominated, especially in southern waters. Four-year-old fish were most abundant in northern areas. Two-year-old fish, rarely caught, occurred in southern areas relatively close to land.

In June, fishing was extensive north and south of the Aleutians in several years and at widely scattered points in the Gulf of Alaska.

Two-year-old fish were usually taken in relatively very small numbers and mainly in southern waters of

the Gulf of Alaska. A few were also caught in the southern Central Bering Sea region. In very late June in 1958, south of Adak, 2-year-olds occurred in very high numbers.

Three-year-old fish occurred more widely than 2-year-old fish. In different years, they occurred throughout the North Pacific and in many areas fished in the Bering Sea as far north as Latitude 58°N. Relative abundance levels were generally low and never exceeded medium levels. Largest concentrations usually occurred south of the Aleutians and eastward into the Gulf of Alaska.

Four-year-old fish were present in most areas sampled, ranging from low to high levels of abundance in different years. In the Bering Sea, they frequently were more numerous in northern than in southern areas. In 1956, limited coverage indicated them to be present in relatively high numbers in the eastern Bering Sea. In 1957, they were present in medium numbers in areas south of the central Aleutians. In the southern areas of the Gulf of Alaska, two sets at widely separated locations failed to catch any 4-year-old fish. According to two sets off the Queen Charlotte Islands farther to the north (at Latitude 55°N, Longitude 135°W), this age group was present at high levels of abundance.

Five-year-olds occurred in much the same areas as 4-year-olds. They usually were most abundant in the western North Pacific and Bering Sea.

In July, sampling in all years but 1957 varied regionally. In 1957, fishing was extensive, covering most of the North Pacific and the southern Bering Sea. Some information on ages of chum salmon is available for the Okhotsk Sea in 1959 and 1960.

The most outstanding feature in July was the increase in numbers of 2-year-old fish in each year, possibly as a result of their greater catchability through growth. Considering all years, this age group was much more numerous in the Western (1959, 1960) and Central Bering Sea (1955, 1956, 1957) regions and in areas southeast of Kamchatka (1960) than in any of the other regions fished. Abundance levels ranged between high and very high. Elsewhere, 2-year-old fish appeared in varying but relatively low numbers. In the Bering Sea east of Longitude 175°W, on the basis of sampling in several years, 2-year-old fish were virtually absent. South of the Aleutians, they were much less numerous than in the Bering Sea, but tended to increase eastward into the Gulf of Alaska. In the latter area they were present only in the eastern and southern areas. Generally, their numbers were larger in southern waters.

In the Okhotsk Sea in July, in the areas fished, 2-year-old fish increased in relative importance northward (1959).

Three-year-old fish in July were considerably more numerous than in June, and were present virtually in all areas fished. Highest concentrations usually were located south of the eastern Aleutians and south of the Alaska Peninsula. In 1960, exceptionally high numbers of 3-year-old fish were caught in these waters. In 1955 and 1956, highest concentrations were reported from the Central Bering Sea region. In the Gulf of Alaska, 3-year-old fish were not as numerous as south of the Alaska Peninsula and their distribution pattern, on the basis of sampling in 1956 and 1957, varied. In the former year, members of this age group were most numerous in the central and southern areas. In 1957, their numbers increased northward. In areas fished in the Okhotsk Sea, low numbers were caught.

Four- and 5-year-old fish occurred generally in July, but appeared to be more numerous in the western regions of the North Pacific and Bering Sea. Further, they were less numerous than in June. The centers of concentration were closer to major land masses than in June, with 4-year-olds being further offshore than 5-year-olds. This is especially apparent in the northwestern areas of the Bering Sea during the latter years and in the northern areas of the Gulf of Alaska in 1956.

In the Okhotsk Sea, 4-year-old fish were dominant in July. In 1959, off the southwest coast of Kamchatka, abundance levels for this age group were high.

The areas fished in August have varied from year to year. Two-year-olds were present generally but in varying numbers. They were most numerous in the western regions, according to sampling in 1957 and 1960, and in the northern and western areas of the Gulf of Alaska, having appeared in relatively larger numbers in the latter region since July. They occurred in low numbers in the Aleutian region, but were still essentially absent in the eastern Bering Sea and southeast areas of the Gulf of Alaska.

The distribution of 3-year-old fish in August was somewhat similar to that in July. In 1956, 1957 and 1958, high to very high numbers of 3-year-old fish were caught south of the Alaska Peninsula. Only very small numbers were present in the eastern Bering Sea. In 1959, sampling in the western Bering Sea

TABLE 26. Ages (weighted) of chum salmon caught by

Month	Latitude (°N)	Year	Longitude																	
			145 E					150 E					160 E					165 E				
			2	3	4	5	6	2	3	4	5	6	2	3	4	5	6	2	3	4	5	6
May	58	1956																				
		1959																				
	54	1957																				
		1958																				
		1959																				
	52	1956																				
		1957																		4	3	2
		1958																				
		1959																				
		1960																				
	50	1957																	1	9	6	3
		1958																				
		1959																				
		1960																				
	48	1957																		6	3	1
		1958																				
		1959																				
		1960																				
	46	1956																				
		1957																				
		1960																				
	44	1960																				
June	60	1956																				
		1959																				
	58	1956																				
		1958																				
		1959																				
	56	1956																				
		1957																				
		1959																				
		1960																		5	4	
	54	1956																				
		1957																				
		1958																				
		1959																				
		1960																	1	5	4	
	52	1957																				
		1958																				
		1959																				
		1960																		7	10	
	50	1956																				
		1957																	2	13		
		1958																				
		1959																				
		1960																		2	5	
	48	1956																				
		1957																				
		1958																				
		1959																				
		1960																		1	1	
	46	1960																				

esearch vessels, 1956–1960, by month and statistical area.

Longitude																									
170° E					175° E					180°					175°W					170°W					
2	3	4	5	6	2	3	4	5	6	2	3	4	5	6	2	3	4	5	6	2	3	4	5	6
		1	-	-																				
										–		1	1											
																					1	16	1	
																				–	–	3	3	–
	-	4	4	-																				
																2	8	1	+					
											1	4	2	-										
–		3		-	+	1	32	2		-	1	27	2	–	–	1	22	3		–	1	3		–
	1	2	1									2	3		–	+	3	4	–					
-	–	15	6	2																				
	1	4	1							–		9	2	1										
					-	1	28	1	-															
															–		4	2						
															–	1	7	1	–					
																	1	1						
																					.	2	2	-
											-	18	1											
																						22	15	-
										–	1	18	4	–							4	4		
																				–	.	12	3	-
															1	6	5	1			–	2	1	-
–	1	24	1		–	–	9**	-		–	1	7	+	–		–	1		–					
	1	6	2		-	–	3	1	–						–		5	2						
										+		–	–	-							–	10	5	-
										1	5	2	1	+							-	2	3	1	-
											1	7	1	–		3	1	1	-	1	2	2	1	
-	–	1	1		–	1	17	1	2		1	4	1	–							–	2	6	1	-
–	–	5	1				3	1	-													9	19	1	1
										–	1	5	1			.	2	1						
	–	8	1	2	-	7	6	2	1	1	6	5	+	+		-	1	2	1					
.	3	5	1	1		1	8	2	1	1	4	14	1	-			8	5	1					
–	–	3	-	–		10	8	1				1	7			–	+	9	1	+				
–	+	5	5			1	9	1	–	–	–	1	1					2	1		.	2	15	1	
					–	12	8	6	1	1		1	-	–											
						5	12	2			3	–	–	–		2	8	3		–	–	3	1	-	1
1	13	1	1							49	7	1	1											
										–	2	8	1									4	–	-	–
	3	7	1		–	+	9	2	1			5	2	–		2	9	1	-					
		6	1	–		2	4	–																
						–	2	3	-															
										-	1	8	1											
										–	–	9	1			13	13	1	–					
										–		8	1	-										

Continued . . .

Table 26.

Month	Latitude (°N)	Year	Longitude																	
			165 W					160 W					155 W					150 W		
			2	3	4	5	6	2	3	4	5	6	2	3	4	5	6	2	3	4	5	6
May	58	1956																	–	–	1	
		1959																				
	54	1957																				
		1958																				
		1959																1	1	4		
	52	1956	–	–	6	8	–															
		1957																				
		1958																				
		1959																				
		1960																				
	50	1957																				
		1958																				
		1959																				
		1960																				
	48	1957																				
		1958																				
		1959																				
		1960																				
	46	1956																--		1	3	
		1957																				
		1960																				
	44	1960																				
June	60	1956																				
		1959																				
	58	1956	–	–	25	11	–															
		1958																				
		1959																				
	56	1956	–	–	4	3	–															
		1957																				
		1959																				
		1960																				
	54	1956	–	–	3	4	–															
		1957																				
		1958											–	2		1	–		2	2	+	–
		1959											–	4	4	+	–					
		1960																				
	52	1957																				
		1958																				
		1959						+	4	2	–	–										
		1960																				
	50	1956																				
		1957											+	1	1	–	–					
		1958											–	3	1	+	–					
		1959						–	7	10	1	–	–	12	5	–	–					
		1960																				
	48	1956																				
		1957																				
		1958																				
		1959																				
		1960																				
	46	1960																				

Continued.

Longitude																				
145°W					140°W					135°W					130°W				
2	3	4	5	6	2	3	4	5	6	2	3	4	5	6	2	3	4	5	6
–	1	4	–	–															
										–	2	9	1	–					
–	3	2	–	–															
										1	8	1	–	–					
										–	–	1	–	–					
–	3	2	+	–															
–	3	1	–	–															
															1	1	1	–	–
										+	3	+	–	–					
										–	1		–	–					
					1	–	–	–	–						1	–	–	–	–	
–	2	5	1	–															
–	17	1	–	–						–	14	29	1	–					
–	1	1	–	–						2	–	1	–	–					
7	2	–	–	–						7	4	–	–	–					
	–	1	–	–															

Table 26.

Month	Latitude (°N)	Year	Longitude: 145 E 2	3	4	5	6	150 E 2	3	4	5	6	160 E 2	3	4	5	6	165 E 2	3	4	5	6
July	60	1957																				
	58	1956																				
		1957																15	6	4		1
		1959																				
		1960																37	7	14	8	
	56	1956																				
		1957																				
		1960											33	9	25	7	–					
	54	1956																				
		1957																				
		1958																				
		1959																				
		1960											26	4	9	1	–					
	52	1956																				
		1957											14	6	6	1	+	5	6	5		
		1958																				
		1959						16	5	23	1	–										
		1960																				
	50	1956																				
		1957											20	1	4	1	–					
		1958																				
		1959						1	1	2	–											
		1960																				
	48	1956																				
		1958																				
		1959						1	–	2	1	–										
		1960						2	2	6	7	–										
	46	1959	–	2	4	1		–	–	1	–	–										
		1960	–	2	4	7	–	+	1	9	2											
August	58	1956																				
		1957																				
		1959																5	1	5	+	
	56	1956																				
		1957																				
		1959																7	6	4	1	
		1960																3	1	7	1	
	54	1956																				
		1957																				
		1958																				
		1959											+	2	1	–		3	3	8		
		1960																				
	52	1956																				
		1957											21	3	4	1	–	5	3	7	1	–
		1958																				
		1959											3	10	11	–		–		12		
		1960											–	6	6	1		1	2	8	2	
	50	1956																				
		1957																				
		1958																				
		1959																				
		1960																	1	1		
	48	1956																				
		1957																				
		1958																				
		1959																				

Continued.

Longitude																									
170° E					175° E					180°					175° W					170° W				
2	3	4	5	6	2	3	4	5	6	2	3	4	5	6	2	3	4	5	6	2	3	4	5	6
															—	—	—	4	—					
										11	41	8	4	—	12	10	2	3	—					
34	27	23	—	—	6	6	17	1	—															
43	14	37	4	—						5	3	—	—	—										
										45	11	2	1	—										
					35	12	3	1	—	34	52	5	7	—	—	2	—	—	—	—	3	—	—	—
55	12	18	4	—																				
										51	37	4	2	—	—	—	1	1	—	—	—	1	—	—
					21	3	1	—	—	62	12	5	—	—	—	1	1	—	—					
26	10	2	1	-	62	3	1	+	—															
					22	5	3	—	—						—	1	1	1	—	—	9	5	1	—
																				2	115	14	1	—
										3	4	1		—										
15	6	3	3	—	67	9	1	—	—						8	1	1	—	—					
1	7	3	—	—	28	14	1	+	—	25	15	2	1	—	—	1	1	—	—					
															—	3	2	-	—	—	16	3	-	
13	3	4	1	—											—	2	3	+	—	2	78	17	1	—
					28	1	1	—	—	40	20	3	—	—	13	10	2	+	—					
					13	3	2	—	—	5	7	—	—	—	29	62	2	—	—					
1	1	2	—	—	1	1	1	—	—	12	27	3	1	—						1	7	1	—	—
26	1	2	2	—	2	5	1	—	—	1	6	5	1	—	1	11	3	+	—					
					7	2	1	-	-						5	3	—	-	-					
										4	2	1	—	—										
															—	—	2	1	—		1	3	2	—
33	14	8	1																					
																				-	—	1		
					24	4	1	—	—															
2	8	7	1																					
15	3	12	3	—																				
															-	—	1	1	—	—	1	1	+	
					11	7	4	—	—	—	1	1	—	—	1	3	3	-	—					
															—	2	1	—	-					
12	1	9																						
2	6	9	1	—																				
															2	6	2	1	+	1	1	1	—	—
					4	14	8	1	—	—	8	6	—	—	1	4	3	+	+					
															1	10	2	1	—	40	56	6	—	—
					—	9	6	5	1	2	11	3	1	—	1	7	3	3	—	1	9	8	1	—
					1	8	8	+	+	1	11	+	—	-										
															1	7	1	—	—	7	13	2	—	—
															—	7	1	-	—					
1	2	4	1	—	1	5	1		-	1	9	1	—											
					—	2	2	—	—	—	—	1	—	—	1	6	2	+	—					
															1	14	2	1						
															2	11	1	-		1	11	1	1	
																4	1							

Continued . . .

Table 26.

Month	Latitude (°N)	Year	Longitude																	
			165° W					160 W					155 W					150 W				
			2	3	4	5	6	2	3	4	5	6	2	3	4	5	6	2	3	4	5	6
July	60	1957																				
	58	1956																				
		1957																				
		1959																				
		1960																				
	56	1956																	13	8	1	
		1957	+	1	5	1	–															
		1960																				
	54	1956												15	14	–	–		8	2	–	–
		1957						1	20	5	1	–	–	4	3	1	–					
		1958																				
		1959											–	13								
		1960																				
	52	1956											–	4	2		–	1	7	2		
		1957	5	18	5	+	–	1	7	3	1	–	–	2	1	–	–					
		1958																				
		1959	+	19	4	–	–	1	25	2	1	–										
		1960																				
	50	1956											3	5	2	–	–	20	9	1	+	
		1957	–	4	10	3	–	21	11	1	–	–	2	3	–	–	–					
		1958																				
		1959	4	44	3	–	–	13	13	1	–	–										
		1960																				
	48	1956											6	2	1	–	–	18	11	2	-	-
		1958																				
		1959						5	6	1	–	–										
		1960	15	21	1	–	–															
	46	1959	4	11	1	–	–															
		1960																				
August	58	1956																2	2	1		
		1957																				
		1959																				
	56	1956	–	1	1	–	–						5	2	1	–	–	3	2	–	–	
		1957																				
		1959																				
		1960																				
	54	1956						–	25	11	-	-	13	14	4	–	–	6	14	1		
		1957	–	1	1	–	–						23	5	1	-						
		1958						1	1	-	–	–	8	8	1		–					
		1959																				
		1960						1	1	2	–	-										
	52	1956						–	4	2	1		3	5	1		-					
		1957	15	27	5	1	–															
		1958	6	15	2	-	-	5	5	1	-	-							1	1		
		1959																				
		1960						–	5	1	-											
	50	1956	3	15	3	–	-	1	8	6			16	5	1	–						
		1957	3	14	3	–	-															
		1958	2	5	1	-	–						5	20	2	-						
		1959																				
		1960																				
	48	1956		2	1	–			4	3	1	–	2	1	1	–						
		1957																				
		1958																				
		1959																				

Continued.

Longitude																				
145°W						140°W					135°W					130°W				
2	3	4	5	6		2	3	4	5	6	2	3	4	5	6	2	3	4	5	6
10	14	11	+	–		+	2	5	+	–										
+	6	1	–	–																
	4	1	–	–		4	4	1	–	–										
-	27	3		–		10	2	–	–	–										
–	2	1	–	–							–	1	–	–	–					
1	24	3	-	–		8	5	–	–	–	2	4	1	–	–					
3	4	-	-	-																
23	11	2	–	–																
11	3	-	–	–		1	–	–	–	–	+	1	–	–	–					
4	4	1	-	-																
2	5	5		-																
24	9	1		–																
18	8	2	–	–																
2	8	1	–	–							1	7	5	–	–					
2	2	–	-	-							–	–	1	–	–					
–	+	–		–																
											–	–	1	–	–					
5	1	–	–	–							–	1	+	+	–					
											–	–	1	-	-	–	–	1	–	–

and northwest areas of the North Pacific indicated medium levels of abundance.

Four-year-old fish were still present in varying numbers in August in almost all areas fished, but were less abundant than in July. In any one year, they never exceeded medium levels of abundance and were most numerous in the western parts of the North Pacific and Bering Sea.

Five-year-olds, except for their absence in catches from the Gulf of Alaska, had much the same distribution as 4-year-olds.

Information on the distribution of the various age groups in September is extremely limited. Most of the fishing in this month was conducted in the Gulf of Alaska, and mainly in 1956. The most apparent feature is the occurrence of 2- and 3-year-old fish in medium numbers in the central areas.

Thus, it would appear that chum salmon of different ages were distributed differently, through May into August. In May, 4-year-old fish, mainly, and 5-year-old fish occurred generally in the North Pacific north of about Latitude 48°N. They were also present in very low numbers in the southern Central Bering Sea region (1958). Some 2- and 3-year-olds were also present, mainly in the Gulf of Alaska. It is presumed that they were also present in the western North Pacific, but were not available to the gear, because of size, to the same extent as in the eastern North Pacific. Throughout all regions, younger fish were more numerous in southern waters. In June, 3-, 4- and 5-year-olds were widely present. Three-year-old fish mainly occurred in the central regions of the North Pacific and the Bering Sea, whereas 4- and 5-year-old fish were relatively more numerous in the Bering Sea. Two-year-old fish were still relatively most numerous in southern areas, especially in the Gulf of Alaska. They also occurred in relatively small numbers in the Central Bering Sea region. In July, 2-year-old fish appeared in all regions but the eastern Bering Sea and the northern and western areas of the Gulf of Alaska. Main areas of concentration were located in the western Bering Sea and southern central Gulf of Alaska. Three-year-old fish, to a large extent, were centered south of the Alaska Peninsula, particularly, and in the central Bering Sea. Four-year-old and 5-year-old fish were generally relatively more numerous in coastal waters than on the high seas. In August, except for 2-year-olds extending their distribution into the northern Gulf of Alaska and the apparent absence of 5-year-olds in the Gulf of Alaska, the distribution pattern for the various age groups was rather similar to that in July.

2. *Mothership Operations*

Information on the distribution of chum salmon of different ages and age composition of high seas catches were obtained from sampling mothership catches for the years 1955–1960. The data varied in detail annually, but nevertheless were based on several thousands of fish. Chum salmon caught by the commercial high seas fishery ranged from three to seven years (two to six winters in the ocean) in age. Six- and 7-year-old fish occurred rarely.

Because of gillnet selectivity, the age composition of chum salmon in the mothership catches will differ from that in the available population. It was pointed out in Section V that the 4.8″ mesh gillnets fished by mothership catcher vessels were ineffective for catching 2-year-olds and 3-year-olds 45 cm in length or less. (From research vessel catches it is known that fish of these ages at times are present in areas where motherships operate.) Accordingly, it is difficult to estimate the relative importance of these age groups in the actual population, using mothership data. Correction for bias in age composition can only be made for fish vulnerable to the gear.

Using age data presented for motherships in Appendix Table G, the extent of the bias in the age composition of commercial catches was estimated. Two series of data, representing catches from areas off southeast Kamchatka in 1957 and 1958, were used. The actual age composition of the catches and the estimated age composition in the available population are shown in Table 27, after eliminating fish under 46 cm in fork length. It is readily apparent that the estimated and actual age compositions for 4-, 5- and 6-year-olds were essentially similar. Three-year-old fish, on the other hand, were not as numerous in the actual catches as they were in the estimated age composition, especially in the 1958 sample.

TABLE 27. Age composition of chum salmon samples from mothership catches and estimated age composition in available population. Chum salmon 45 cm in length or less were not considered.

Region and time period	Total age composition (percent)			
	3	4	5	6
West of 170°E, June 1957				
in sample	6	66	20	8
estimated	7	67	19	7
West of 170°E, June 1958				
in sample	7	75	17	1
estimated	11	73	16	1

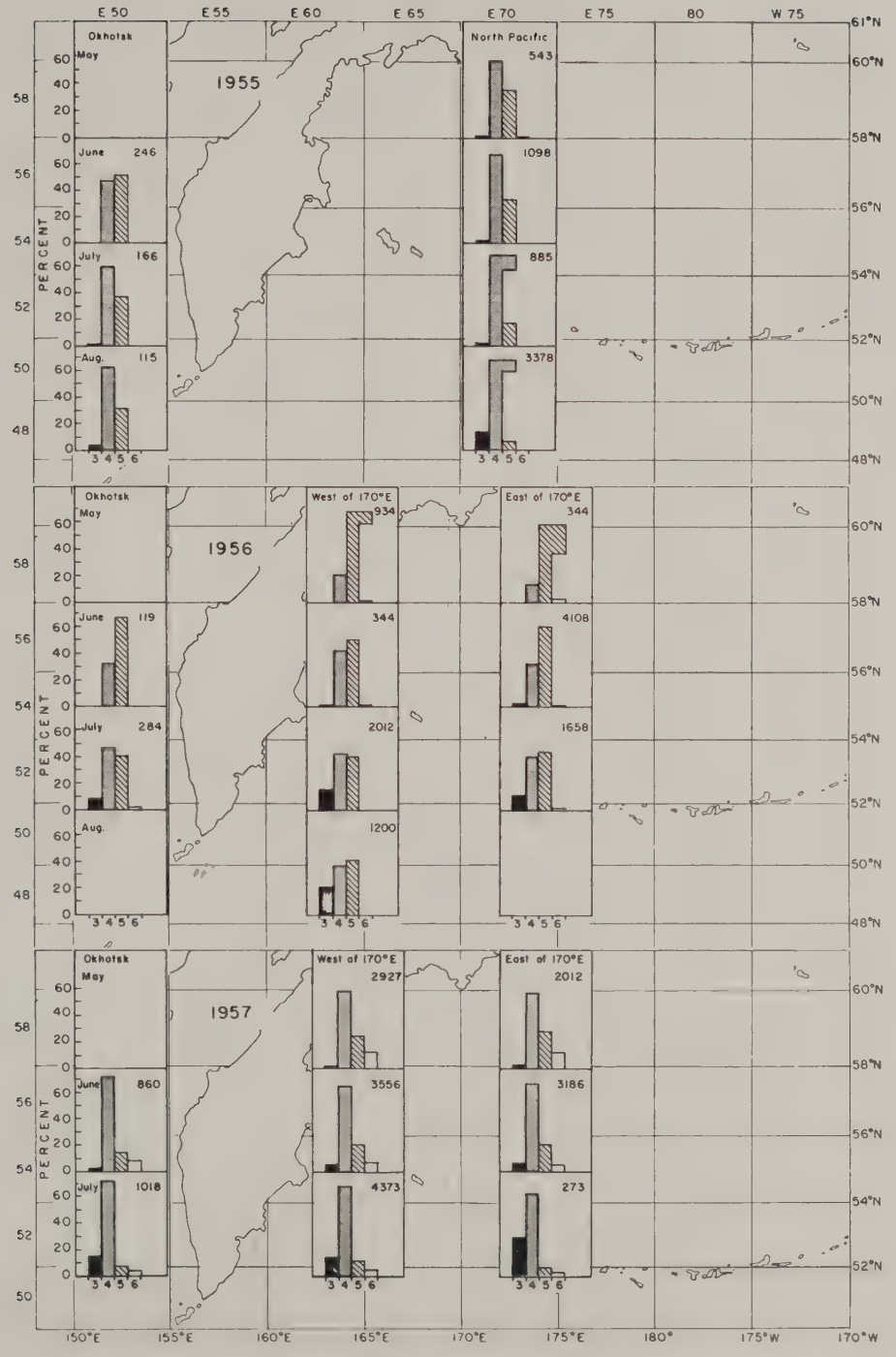

FIGURE 21. Age composition (percent) of chum salmon samples from the mothership fishery, by region and by month, 1955–1960. Sample size is indicated by the numerical insert for each month.

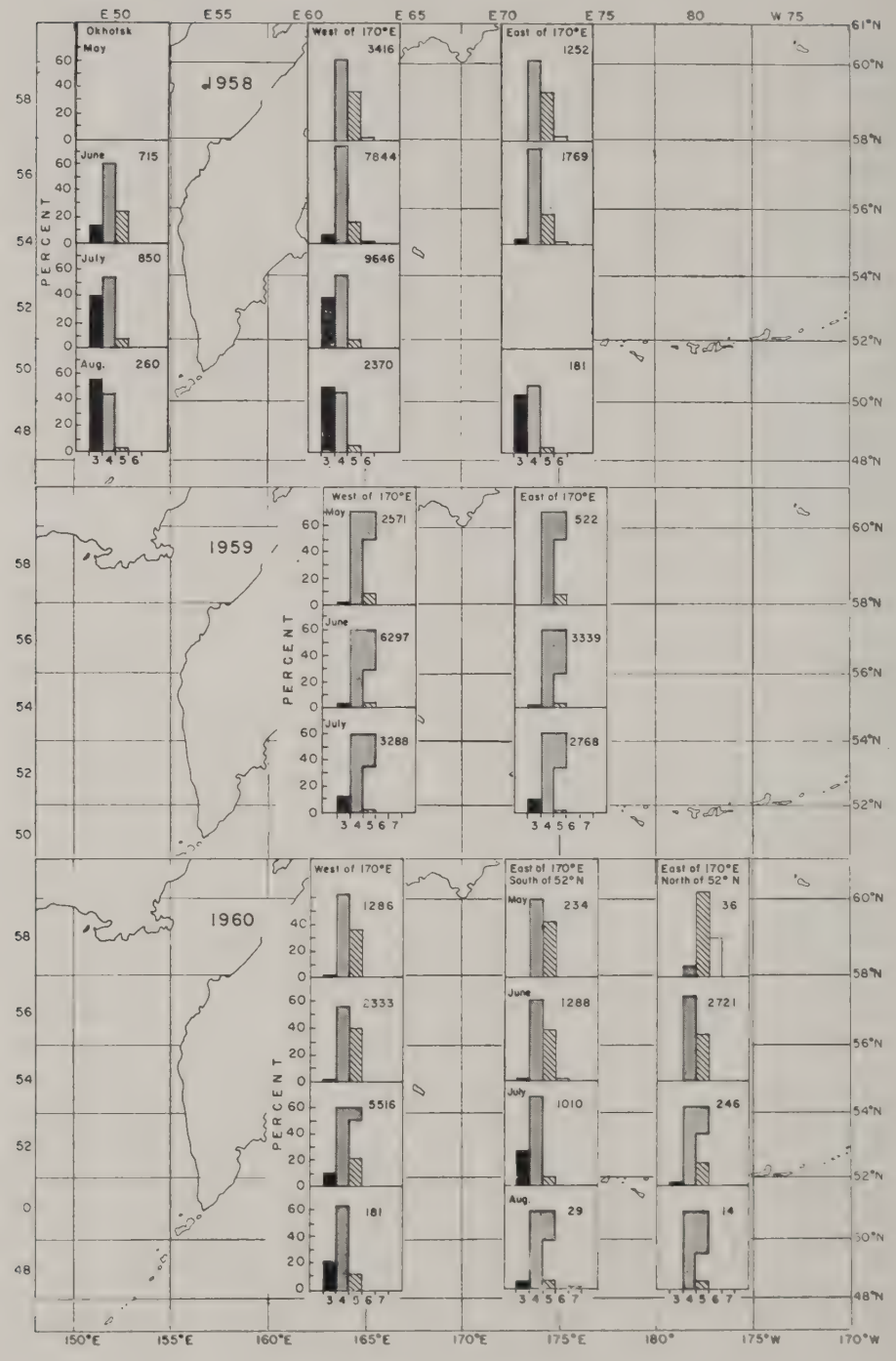

FIGURE 21. Continued.

The age composition of samples from the mothership fishery is shown by fishery region and by month for the years 1955 through 1960 in Figure 21. Supplementary age data are available for 1956, 1957 and 1958 by statistical area and selected 10-day periods and are illustrated in individual figures for each year (Figures 22–24).

Age composition data for 1955 were grouped by month according to two regions, the North Pacific Ocean and the Okhotsk Sea.

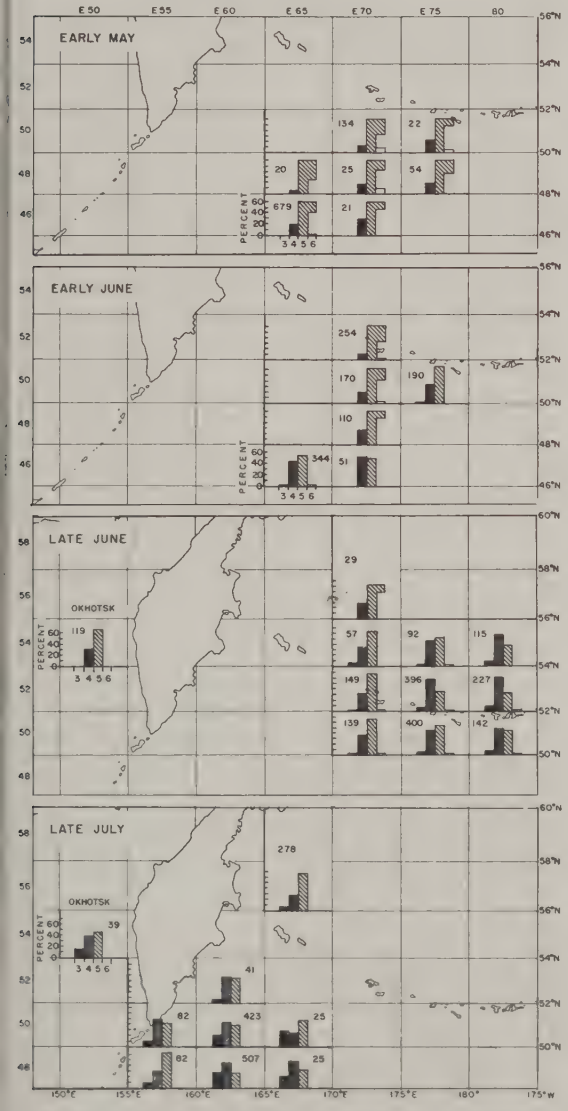

FIGURE 22. Age composition (percent) of chum salmon samples from the mothership fishery, by statistical area and selected 10-day periods, 1956.

In the North Pacific in May, when the fishery operated south of the western Aleutians, mainly in areas E6548 and E7048, 4-year-olds were dominant, making up almost 60% of the samples, and were followed by 5-year-olds (38%). Three-year-olds mainly, and a few 6-year-olds, made up the balance of the samples. During June and July, as the fleets moved westward, the percentages of 3- and 4-year-olds increased, while that of 5-year-olds decreased.

Similar changes in age composition also occurred in the Okhotsk Sea, but the monthly percentages of the age groups differed from those in the North Pacific. During June, July and August, the percentages of 5-year-olds were higher in the Okhotsk Sea than in the North Pacific; those of 4- and 3-year-olds, lower.

For the years 1956 to 1958, inclusive, the age composition data are available by month for three regions:

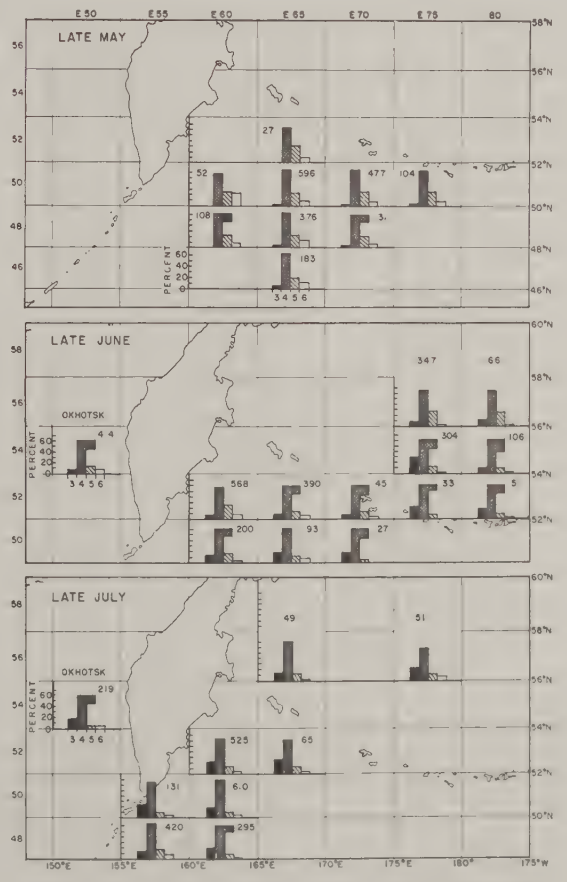

FIGURE 23. Age composition (percent) of chum salmon samples from the mothership fishery, by statistical area and selected 10-day periods, 1957.

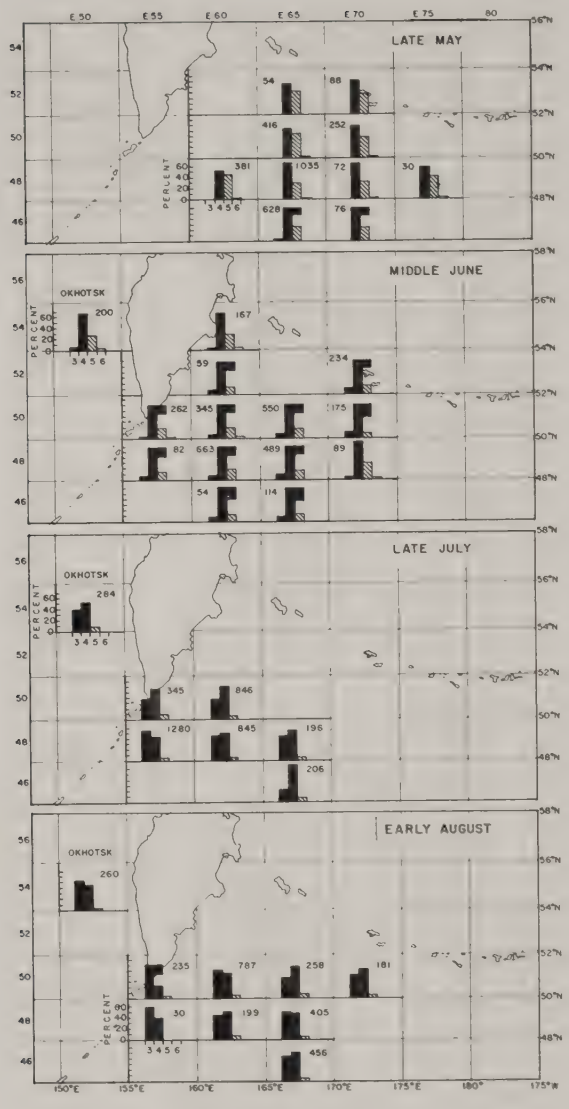

FIGURE 24. Age composition (percent) of chum salmon samples from the mothership fishery, by statistical area and selected 10-day periods, 1958.

east of Longitude 170°E, west of Longitude 170°E to Kamchatka and the Okhotsk Sea.

In 1956 (unlike 1955 when 4-year-olds were dominant), the most important age group was 5-year-olds, particularly early in the season. In May, 5-year-olds formed approximately 80% of the samples and were followed by 4-year-olds, mainly, with few 6-year-olds. Three-year-olds were absent in the samples. With each successive month, the percentage of 5-year-olds decreased and the percentage of 3-year-olds increased. West of Longitude 170°E, 3-year-olds in August formed 21% of the samples.

In the Okhotsk Sea from June to July, according to smaller samples, the changes in age composition were similar to those in the North Pacific.

The detailed data indicate that the percentages of the age groups differed between areas (Figure 22) and between periods. Except during early May, when samples for most areas were small, the figures are based on large samples. During early May and early June, when fishing was mainly conducted south of the western Aleutians, the percentages of 5- and 6-year-olds increased northward and westward. During late June in the Central Bering Sea region and south of the central Aleutians, 5-year-olds were dominant in western and northern areas, 4-year-olds in eastern areas. Three-year-olds, although relatively few, formed a higher percentage of the samples from the eastern areas than from the western areas. During late July, comparing areas southeast of Kamchatka with those in the western Bering Sea, the age composition of chum salmon varied considerably, some of this variation probably being due to the small size of some samples. In the Bering Sea (areas E6558 and E6556 combined), 5-year-olds dominated and were followed by 4- and 3-year-olds, successively. In most areas southeast of Kamchatka, the percentages of 3- and 4-year-olds were higher.

In the Okhotsk Sea in late June, the age composition of chum salmon was similar to that observed for the North Pacific and the Western Bering Sea region. Late July samples were too small to be considered useful.

In 1957, as in 1955, 4-year-olds were again dominant (Figure 21). The rather high percentage of 6-year-olds is attributed to the large number of chum salmon which failed to mature as 5-year-olds in 1956.

West of Longitude 170°E, from May into July, the percentages of 3- and 4-year-olds increased progressively while those for 5- and 6-year-olds decreased. Since only a small portion of the July catch in this region was made in the Western Bering Sea region, the data are considered to show changes in the age composition of chum salmon in waters southeast of Kamchatka and southwest of the western Aleutians.

In the region east of Longitude 170°E, the age composition of chum salmon caught in May and June was very similar to that observed for the region west of 170°E. Judging from catch statistics (Appendix Table D), the May samples presumably represented

ish caught south of the Aleutians; June samples, fish caught in the Bering Sea as well as south of the Aleutians. In July, however, the bulk of the catches in this region was made in the Bering Sea, and accordingly the age data may be more representative of chum salmon north rather than south of the Aleutians. Four-year-olds were still dominant, however, but 3-year-olds made up 29% of the samples, a much higher proportion than during June in this region or during July in the region west of Longitude 170°E.

In the Okhotsk Sea region, the changes in the age composition pattern in general were similar to those observed in the regions east and west of Longitude 170°E.

Detailed age composition data by statistical area in 1957 is based on samples collected during late May, late June and late July (Figure 23). During late May, when fishing took place southwest of the Aleutians, 4-year-olds were most numerous, forming between 56% and 74% of the samples, followed by 5-year-olds, mainly, and 6-year-olds. Three-year-olds were present only in samples from areas south of Latitude 52°N and east of Longitude 165°E (Appendix Table F) and formed a relatively small percentage of the samples. Between Longitudes 165°E and 170°E, the percentages of this age group increased southward. During late June in both the North Pacific and the Bering Sea regions, 4-year-olds continued to be dominant. In each region, however, 3-year-olds ranked second in relative importance in areas adjacent to the Aleutians and were gradually supplanted in importance by 5-year-olds westward from this sector in the North Pacific and northward in the Bering Sea. In the Okhotsk Sea, for the same time period, the age composition of chum salmon was somewhat similar to that in areas of the North Pacific and Bering Sea approaching Kamchatka and the northwest coast of the Bering Sea, respectively. During late July, with some changes in the areas fished since late June, 4-year-olds dominated. In virtually all areas sampled in the North Pacific, Bering Sea and Okhotsk Sea, they were followed in importance by 3-year-olds, 5-year-olds and 6-year-olds, in that order.

Information on the age composition of chum salmon in 1958 is available only for the Okhotsk Sea and North Pacific regions (Figure 21). Mothership operations in that year did not extend into the Bering Sea, nor were they extensive east of Longitude 170°E after June.

The monthly age composition in 1958 in each region differed from that observed in previous years. The percentage of 4-year-olds, instead of increasing through the fishing season as in other years, was highest in June, and then declined. Accompanying this trend, the relative proportion of 3-year-olds in the samples increased and was higher than in other years.

Detailed data for 1958 indicate that the age composition of chum salmon differed to some extent between areas and time periods (Figure 24). During late May, mainly in waters between Longitudes 165°E and 175°E and Latitudes 46°N and 54°N, the samples virtually consisted of 4- and 5-year-olds only. Four-year-olds dominated, but the percentage of 5-year-olds increased from south to north. During mid-June, when fishing in the North Pacific was more extensive, 3-year-olds were generally present. They tended to be somewhat more numerous in the samples from the northern areas, especially to the eastward. During late July southeast of Kamchatka, their numbers increased and they were most numerous between Latitudes 48°N and 50°N. During early August, 3-year-olds were dominant in areas adjacent to Kamchatka, but were displaced by 4-year-olds further offshore. These temporal and spatial variations in the age composition of chum salmon were presumably associated with maturing chum salmon having different migration times and destinations.

For 1959, the monthly age composition data were grouped according to regions east and west of Longitude 170°E (Figure 21). Fishing started in the North Pacific, mainly south of Latitude 50°N, in late May and continued through July, with some shift to the northwest. Some effort, mainly in July, was also diverted into the Bering Sea north of Latitude 56°N. The age composition of the samples through the fishing season varied only slightly. The outstanding difference from other years was the uniformly very high percentage of 4-year-old fish, explainable by the relatively large numbers of 3-year-olds in 1958.

Information on the monthly age composition of chum salmon in 1960 by region is available in slightly more detail than for previous years; samples collected east of Longitude 170°E were divided according to waters south and north of Latitude 52°N (Figure 21).

West of Longitude 170°E in May, 4-year-olds formed the dominant age group (65%), followed by 5-year-olds (33%) and 3-year-olds (2%). The bulk of the catches during this period was made in areas E6548 and E6550. Through June into August, the percentage of 4-year-olds was reasonably stable and considerably higher than that of either 3- or 5-year-olds. Through this period, the usual monthly increase in the percentage of 3-year-olds and decrease in percentage of 5-year-olds, observed in other years, occurred.

Since only a small portion of the total catch was made in the Bering Sea, the data are principally indicative of changes in the North Pacific region.

East of Longitude 170°E and south of Latitude 52°N in May, only 4- and 5-year-olds were present in the samples, the former being dominant, but not to the extent that they were west of Longitude 170°E. In June and especially July, 3- and 4-year-olds increased in importance while 5-year-olds decreased. August samples, while very small (29 fish), showed a large predominance of 4-year-olds.

Samples for the region east of Longitude 170°E and north of Latitude 52°N are only adequate in size for June and July. Judging from the catch statistics, these samples probably represent catches from waters between Longitudes 180° and 175°W. In each of these months, 4-year-olds were the most important age group, forming 65% of the samples in June and 81% in July. These percentages exceeded those for 4-year-olds in the other two regions for corresponding months. The remaining portion of the samples in the two months consisted essentially of 5-year-olds. The virtual absence of 3-year-olds is noteworthy.

From the foregoing, it would appear that the distribution pattern of chum salmon of different ages in the North Pacific, Bering Sea and Okhotsk Sea from May into August, as indicated by sampling mothership catches, was basically similar from year to year in spite of some annual variation in the areas fished. In each year from 1955 to 1960, inclusive, 3-, 4-, 5- and 6-year-olds were present in the catches. During May, in the North Pacific at least, 5- and 6-year-olds were relatively more numerous in waters approaching coastal areas than further offshore. There was a tendency for their numbers to decrease southward. Four-year-olds, usually dominant, were present generally. Three-year-olds were relatively more numerous in offshore than in coastal areas. During subsequent months and as late as August, in all regions, the proportion of older fish declined and that of younger fish increased. These spatial changes in the relative proportion of chum salmon of different ages presumably are due to the emigration of older fish, and therefore more likely to be maturing, from the high seas areas towards coastal areas, thus leaving a progressively larger residue of younger, presumably immature, fish to form the high seas population.

While the distribution pattern and the ages of chum salmon present in the catches were quite similar from year to year, the relative importance of the different age groups varied annually. In each year except 1956, 4-year-olds dominated, indicating that chum salmon caught in the North Pacific and adjacent seas were principally 4-year-cycle fish. In 1956, however, 5-year-olds were dominant, indicating a very strong yearclass in 1951. The unusually high percentages of 3-year-olds in 1958, 4-year-olds in 1959, and 5-year-olds in 1960 would also indicate that 1955 was also an unusually strong yearclass.

3. *Landbased Region Operations*

Information on age composition of chum salmon in the landbased region is available for 1957–1960 from research and training vessels fishing commercial gillnets authorized for the region. The data for each year are illustrated in Figure 25 by month and according to catches from areas north and south of the Japan-Soviet treaty line, which extended from Nossapu Peninsula, Hokkaido, to a point at Latitude 45°N, Longitude 155°E, thence eastward along Latitude 45°N (Figure 3). The data upon which Figure 25 is based are given in Appendix Table F. In all years but 1957, the data were obtained from acceptably large samples. Even though coverage in each year differed somewhat in time and area, the data provide valuable information on the relative proportions of the various age groups available to the gear from May into August. Since gillnets fished in the landbased region had smaller mesh sizes than gillnets fished in the mothership area, the smaller, younger fish would likely be better represented in the catches made in the landbased region. Thus, the age compositions of the catches made in the two regions are not directly comparable.

Chum salmon ranging in age from three to six years were caught in the landbased areas. Annually, 4-year-olds formed the most important age group, usually followed by 3- and 5-year-olds, in that order.

The percentages of the various age groups in the samples from areas north (Area A) and south (Area B) of the Japan-Soviet treaty line changed monthly in much the same way. In May, 4-year-olds were largely dominant, followed by 5-year-olds. In 1958, the only year when samples were available from areas both north and south of the treaty line in May, 3-year-olds were more numerous in the southern area. Through June into August, 4-year-olds maintained their dominance, 5-year-olds declined in importance and 3-year-olds increased. An exception to this monthly pattern was noted for 1958 when the percentage of 3-year-olds in the northern areas declined from July to August. Two-year-olds were absent in the catches in each year.

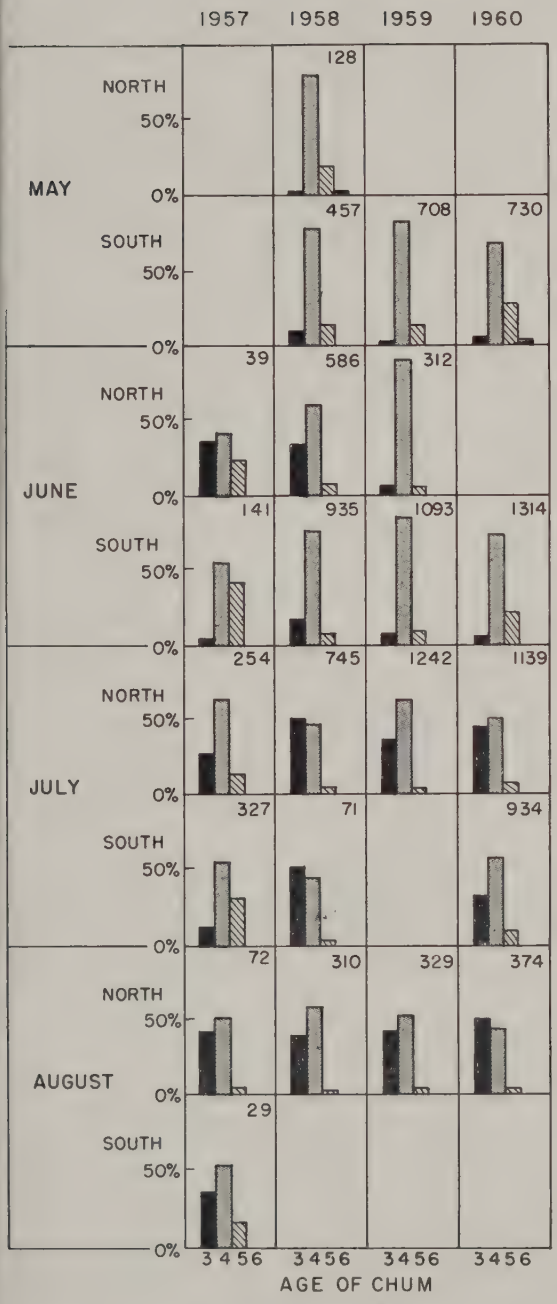

FIGURE 25. Age composition (percent) of chum salmon caught by research and training vessels using 4.5″ mesh gillnets in the landbased region, 1957–1960, by month.

4. *Summary*

Research vessels caught mainly 2- to 5-year-old chum salmon and mothership operations mainly 3- to 5-year-old chum salmon. Older fish were also caught, but these formed only a very small proportion of the catches. Combining the information on the distribution of each age group from research and commercial vessel operations for all years, a generalized distribution pattern for the various age groups can be constructed for the period May into August. Although the abundance indices for the same age group obtained from each source of information are not directly comparable because of gear selectivity and annual fluctuations in yearclass strengths, they do nevertheless indicate some pronounced annual features in the distribution of each age. Figure 26 schematically illustrates the occurrence and distribution pattern of each age group by month through the study period.

Chum salmon in their first year of ocean residence are too small to be caught by gillnets used by either research or commercial vessels. During the summer months, most members of this age group would be present in coastal waters (Manzer, 1956; Mihara, 1958). Some offshore movement must occur shortly thereafter since some fish in their first ocean year were caught in the western Gulf of Alaska during mid-September (Hartt, 1962). The extent of their offshore distribution thereafter is not known.

In May, 2-year-olds taken only by research vessels were caught in the southeastern areas of the Gulf of Alaska only. Three-year-olds were widespread across the western and central areas of the North Pacific northward to about Latitude 52°N and generally throughout the eastern part of the Gulf of Alaska, where they were relatively most abundant. In all areas, their numbers tended to increase southward. Four- and 5-year-olds were present in virtually all waters fished by the different operations. However, 4-year-olds were most numerous south and southwest of the Aleutians; 5-year-olds, to the northwest of these areas. Six-year-old fish were caught only west of the eastern Aleutians in the North Pacific.

Following May, as the southern limit of salmon shifted northward, the availability and distribution of the different age groups changed monthly. Two-year-olds became more numerous in southern waters of the Gulf of Alaska and were also present in the central Aleutians and southern Central Bering Sea region. By July, they were present in relatively larger numbers than in June throughout the North Pacific, including the Gulf of Alaska, and in the Bering Sea. Centers of concentration during July and August were located in the southwestern areas of the Gulf of Alaska and eastern Aleutians and in the western areas of the Bering Sea and North Pacific.

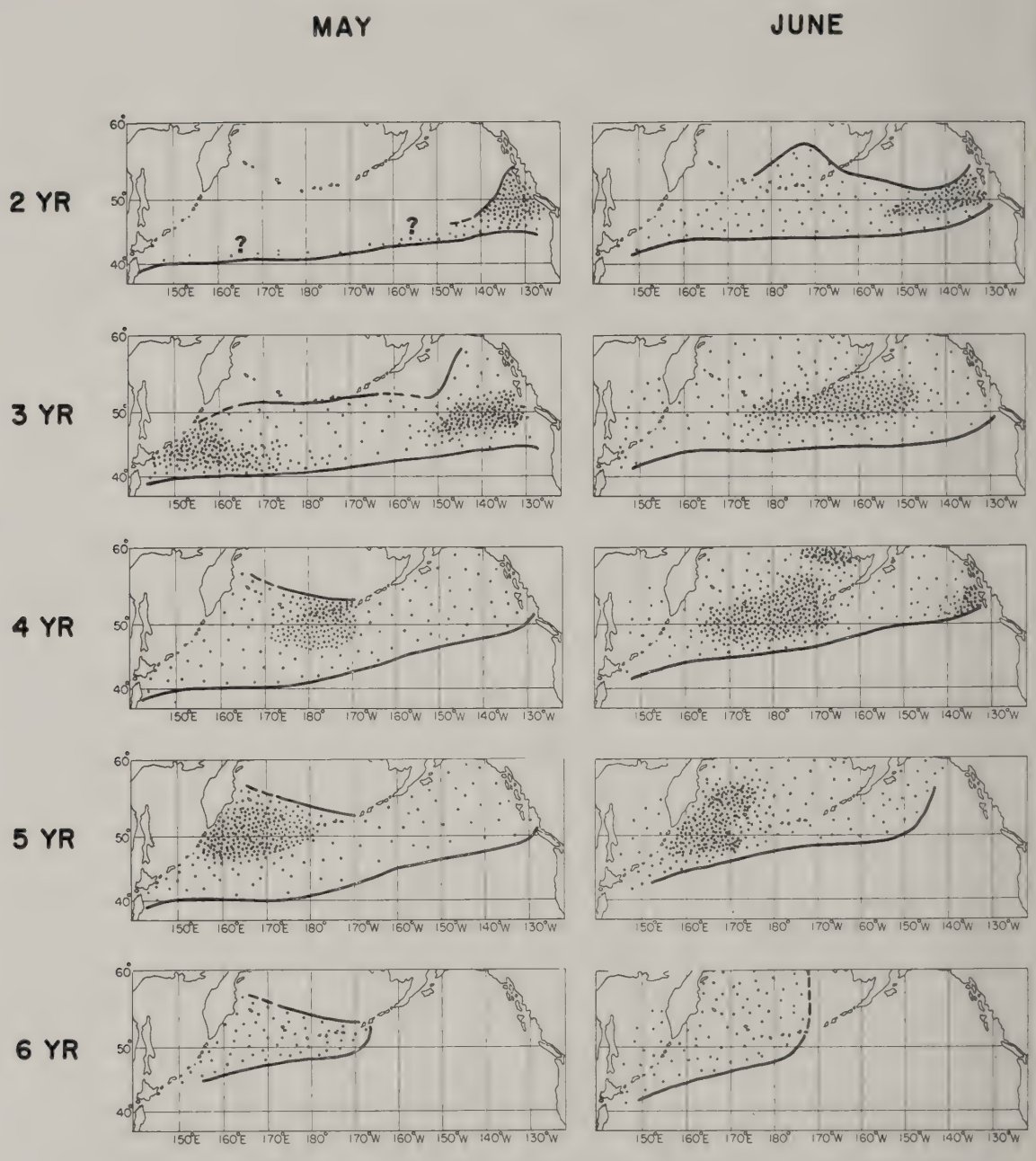

FIGURE 26. Schematic diagram showing the distribution of chum salmon of different ages in the North Pacific and Bering Sea, by month.

Three-year-olds, following May, throughout the North Pacific and the Bering Sea, progressively increased in numbers northward. During July and August, they were relatively numerous in the Western Gulf of Alaska region and south of the eastern Aleutians and in the Western Bering Sea region. Also, in most instances, 3-year-olds in the western areas of the Bering Sea and North Pacific were less abundant than 2-year-olds in the same areas, or than 3-year-olds in the important North Pacific areas further to the east.

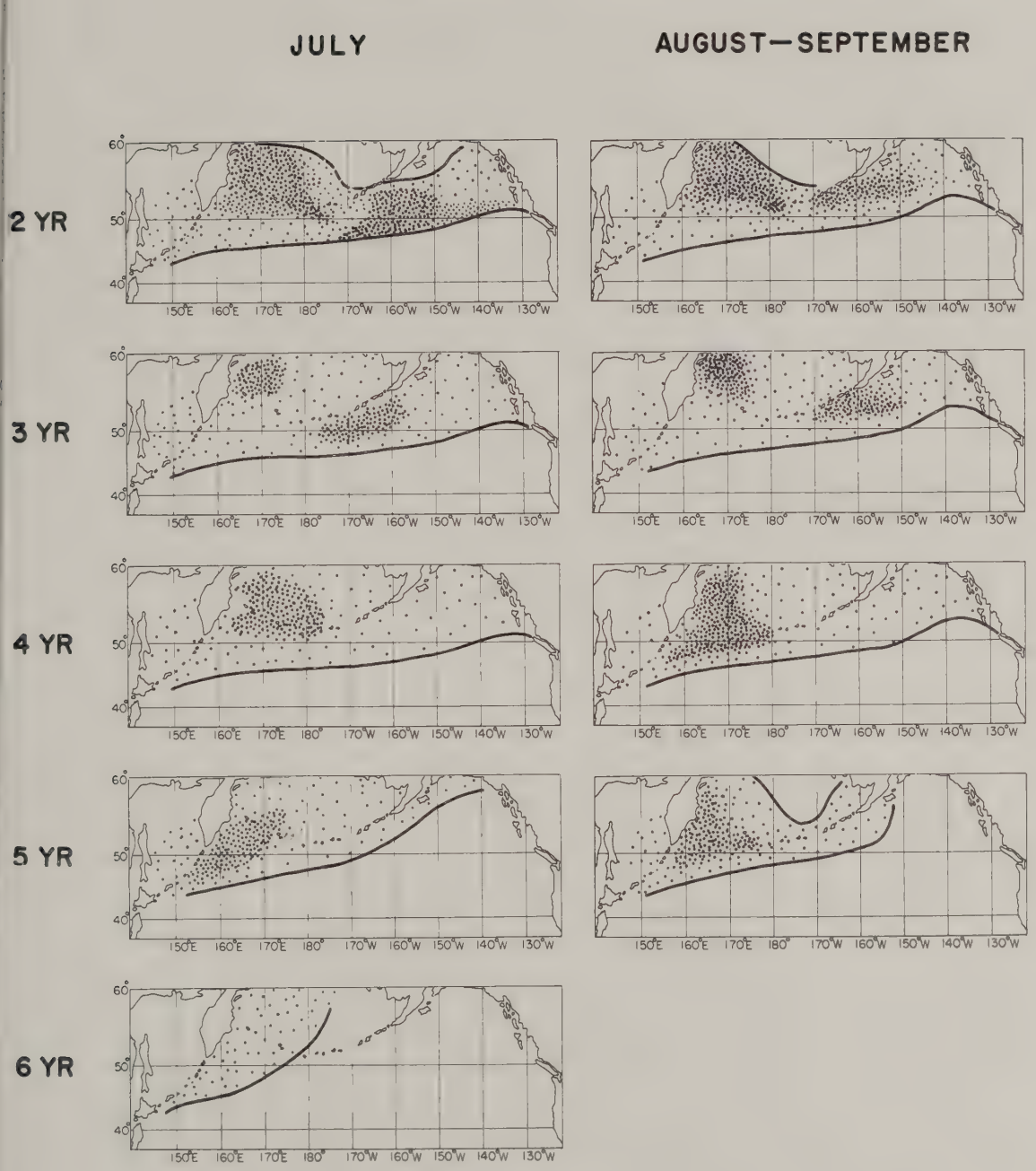

FIGURE 26. Continued.

Four-, 5- and 6-year-olds, while having somewhat different distribution patterns, increased in relative numbers coastward from the high seas areas. The older the age group, the closer to a major land mass was its center of concentration, regardless of the month. Since most 4- and 5-year-olds, the latter age group particularly, and virtually all 6-year-olds in most years can be considered to be maturing fish, the coastward shift in the centers of abundance is to be expected. Four- and 5-year-olds were considerably more numer-

ous in the western than in the eastern areas of the Bering Sea and the North Pacific. Five-year-olds were virtually absent in the Gulf of Alaska in August. Six-year-olds were only caught west of about Longitude 175°W in the Bering Sea. In the North Pacific they apparently did not occur as far to the east as in the Bering Sea.

In the Okhotsk Sea, mothership catches for June and July included 3-, 4-, 5- and 6-year-old fish. Limited fishing by research vessels in July, in addition to 3-, 4- and 5-year-olds, caught 2-year-olds. The number of 2-year-olds increased northward. These catches indicate that the occurrence of these age groups was continuous from the western Pacific into the Okhotsk Sea.

D. Length of Chum Salmon in Mothership Catches

The fork length frequency distribution and mean length of chum salmon caught by mothership operations are available for 1957 to 1960 and are given in Appendix Table G. The length data are tabulated for each year by large regions, by age, by sex and by month. The number of fish in most samples from each region is extremely large.

In view of the large mass of data it has been impossible to analyze the length data in detail. Only a superficial study of the lengths of chum salmon in the various regions was made and the main features detected. To show readily discernible differences, the range in length, position of major modes and the mean lengths of chum salmon are illustrated in Figure 27 by region, year, month, age and sex. The modes are based on unsmoothed frequency data and are shown to the closest centimeter. When considering these data, it must be pointed out, as it was for sockeye salmon, that the sizes of chum salmon of the same age can be variously influenced by ocean environment, by genetic characteristics and by changes in size and shape as secondary sexual characteristics develop with approaching maturity, and that the selectivity of commercial gillnets upon fish of varying sizes limits the data.

The mean length of chum salmon of different ages in mothership samples did not differ greatly. Average mean length to the nearest centimeter for 3-year-olds was 50 cm; for 4-year-olds, 54 cm; for 5-year-olds, 56 cm; for 6-year-olds, 58 cm. Within each age group, males were usually slightly larger than females.

The mean length of chum salmon of different ages caught in the different regions either increased through the season or remained reasonably constant. Notable exceptions are 4- and 5-year-old fish east of Longitude 170°E (Aleutian region) in 1958 and 4-year-old females in the Bering Sea in 1960. In each of these cases the mean lengths decreased with succeeding months.

Considerable variation in modality occurred in the length frequency distributions of fish of different ages in different months and regions. Usually only one mode was present in each age group. This mode either remained reasonably fixed in position or shifted to the right, indicating the presence of larger fish. Exceptions occurred in 1957 in 3-year-old males in the Kamchatka-Kuril region (west of Longitude 170°E) and in 4-year-old males and females in the Aleutian region (east of Longitude 170°E); in 1958 in 3- and 4-year-old males and females in the Kamchatka-Kuril region; in 1960 in 4-year-olds in the Bering Sea. In each case, the mode shifted in favour of smaller fish. This phenomenon is most apparent for 4-year-old fish in regions and months (June and July) when relative abundance levels fluctuated. Presumably the shifting of the modes is related to occurrence of stocks having different length compositions and to the migrations of immature and maturing individuals.

E. Recapitulation

The high seas distribution of chum salmon was derived from the same sources of information and fishing operations as were used for sockeye salmon. Not unlike sockeye salmon, chum salmon varied annually, seasonally and spatially in relative abundance, age composition and in the proportions of maturing and immature individuals. A basic seasonal distribution pattern nevertheless was apparent. This pattern for May through August can be grossly described as follows.

In May, chum salmon are widely distributed in the North Pacific. Their southern limit is located at about Latitude 40°N in the western Pacific and at about Latitude 46°N in the eastern Pacific. Within this vast territory, chum salmon are most abundant south and southwest of the western Aleutians. Their numbers decline in all directions from this center, the drop being more marked to the south and east where abundance levels are relatively low. West of about Longitude 170°E and north of about Latitude 50°N eastward into the Gulf of Alaska, catches consist virtually of maturing fish. Their importance decreases southward and eastward until finally in the southern latitudes immatures dominate.

Accompanying this transition in the proportions of maturing and immature fish is a northwest to southeast

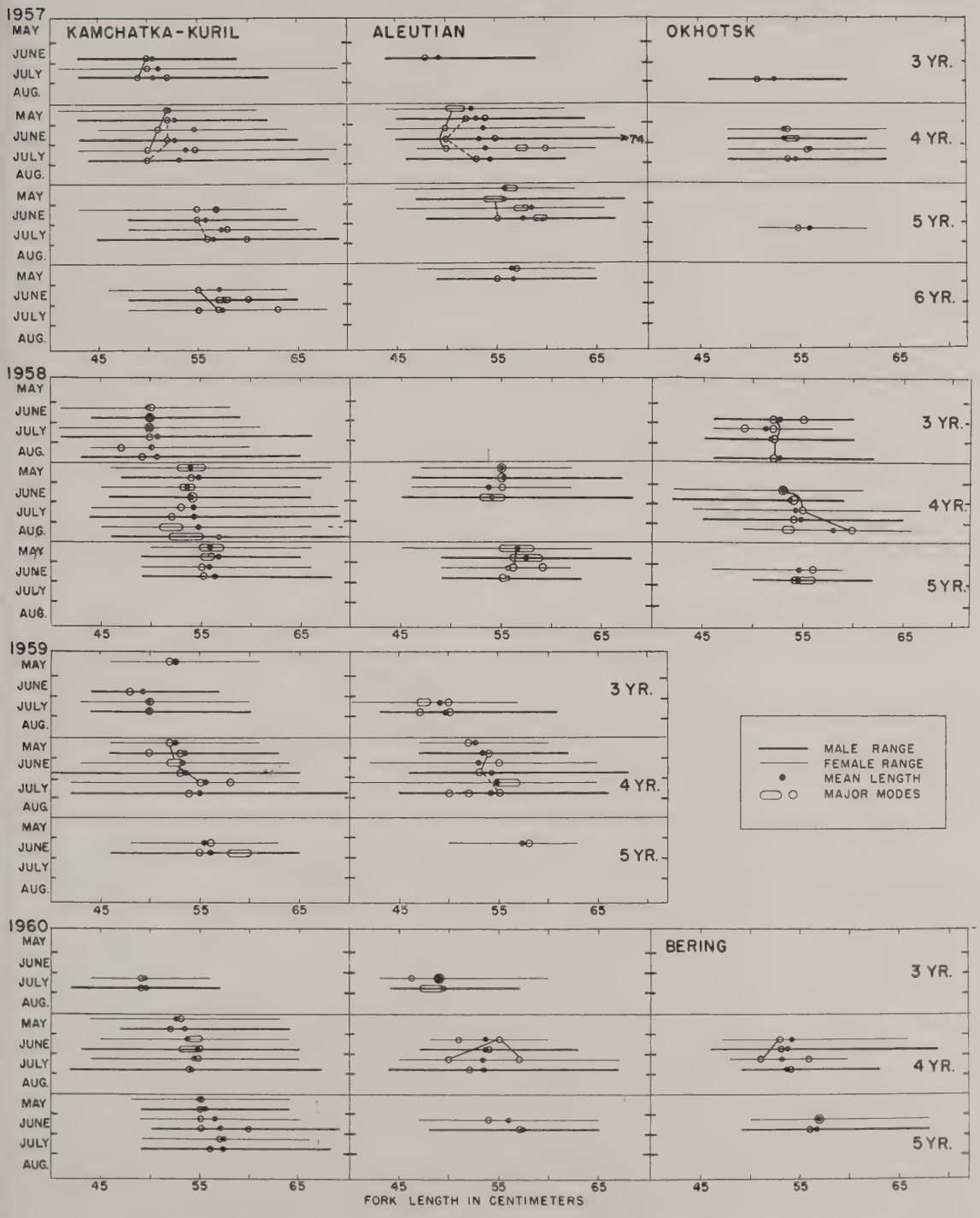

FIGURE 27. Range, mean length and major modes of male and female chum salmon of different ages in samples from the mothership fishery, 1957–1960.

stratification in May of chum salmon in order of decreasing age. In the western Pacific, the catches consist largely of 4-, 5- and 6-year-olds. Three-year-olds occur mainly south of about Latitude 50°N and in the Gulf of Alaska. Two-year-olds are mainly caught in the southeast areas of the Gulf, although they are probably present further west in the southern latitudes, also.

The occurrence of chum salmon in the Bering Sea in May is not fully known, although some have been taken as far north as Latitude 55°N in the central area during the latter part of that month. Chum salmon in this area are mainly maturing and are relatively low in numbers.

Since chum salmon were present south of Kamchatka in May, it can be presumed that some chum salmon, excluding those in their first summer in the ocean, are in the Okhotsk Sea in May, especially in the southern areas. Also, since chum salmon in the extreme western Pacific are mainly maturing, it is reasonable to think that those in the southern Okhotsk Sea are largely maturing, because of the close proximity of the two areas.

In June, chum salmon occur in greater numbers over a wider area of the North Pacific than in May. They are still most numerous in the western Pacific areas and consist mainly of maturing fish of four, five, and six years of age. South of the Aleutians, abundance levels fluctuate, but tend to be relatively high. The fluctuations are probably due to movements undertaken by maturing individuals and to an increase in the availability of immatures of two and three years of age in the area. In the Gulf of Alaska, chum salmon are not as numerous as in regions to the west. The proportions of immature and younger fish increase southward. In the coastal areas of the Gulf, considerable variation in abundance levels and in the proportions of maturing and immature fish occurs.

In the Bering Sea in June, chum salmon occur generally, but are not as numerous as in the northwest Pacific or south of the Aleutians. Abundance levels are highest in the south-central areas and decline coastward from this point. Immature and younger fish, 2-year-olds as well as 3-year-olds, are now present, indicating a northward movement into the Bering Sea since May. The fraction of the population which these age groups form decreases coastward.

In the Okhotsk Sea southwest of Kamchatka, chum salmon in June are more concentrated than in either the Bering Sea or the North Pacific. Peak abundance levels occur in early June and decline thereafter. A large proportion of the chum salmon is made up of maturing fish, either four or five years of age.

In July, chum salmon do not occur as far south as in June. In the North Pacific, they are most abundant southeast of Kamchatka and south of the Aleutians and south of the Alaska Peninsula eastward into the Gulf of Alaska. Chum salmon are more abundant in July than in June in the latter two areas, indicating a continuing increase in numbers since May. This increase in brought about by an influx of immature, 2-and 3-year-olds to the areas. The latter age group tends to be relatively more important in northern waters; the former age group, in southern waters. South and east of the main territory occupied by chum salmon, abundance levels decline.

Immatures constitute the bulk of the high seas population in the North Pacific in July. Their importance, however, decreases as coastal areas are approached, thus reflecting the emigration of maturing individuals from the high seas areas. This emigration is also indicated by the changing distribution pattern of the older chum salmon.

In the Bering Sea in July, chum salmon are most abundant in the Central Bering Sea region, thus extending northward the large concentration of chum salmon south of the Aleutians. Their numbers decline in all directions from the Central Bering Sea region, the drop being more pronounced eastward. In the eastern areas of the Bering Sea, chum salmon are relatively few. The population in the western areas of the Bering Sea consists of 2-year-old, immature, primarily, and 4-year-old, maturing individuals. North and east the fraction of immatures declines.

In the Okhotsk Sea in July, off southwest Kamchatka, chum salmon density levels are lower than in June, but usually higher than in other areas fished. The proportion of immatures increases from south to north and through the month. Maturing fish continue to dominate.

In August, chum salmon are generally less numerous than in July and immatures form a very large portion of the population in all areas but those close to major land masses. This is to be expected as maturing, older fish continue to evacuate the high seas areas. The distribution pattern of the main body of chum salmon, however, is slightly different from July, as it now occupies a less extensive area to the south in the North Pacific and to the north and east in the Bering Sea.

In the extreme western areas of the Bering Sea and North Pacific, 2-year-olds and 4-year-olds tend to be the dominant age groups in August. Two-year-olds also form a substantial part of the population in the western areas of the Gulf of Alaska. Three-year-olds, while occurring generally, are dominant south of the eastern Aleutians. Four-year-olds and 5-year-olds occur generally, but they are relatively more numerous in the western halves of the North Pacific and Bering Sea. Five-year-olds are virtually absent in the Gulf of Alaska.

In the Okhotsk Sea in August, chum salmon continue to decline in numbers from July. As maturing fish pass through the area en route to their spawning areas, it can be expected that immatures will form an even larger fraction of the population in August than in July.

The southern limit of chum salmon distribution has shifted northward with each successive month since May. As with sockeye, this shift coincides with the warming of the surface waters from the south. The southern limit of chum salmon distribution in August is about Latitude 44°N in the western Pacific and about Latitude 52°N in the eastern Pacific.

VIII. PINK SALMON

A. Catch and Relative Abundance

1. *INPFC Research Vessel Operations*

The catches made by each research vessel for the period 1955–1960 are listed by set in Appendix Table A.

The changes in the relative abundance of pink salmon, according to statistical areas and 10-day periods, are shown for these years in Appendix Figure B-3. The relative abundance indices for individual sets, on which this figure is based, are presented in Appendix Table C. The index used is the number of pink salmon caught per 3,000 feet of INPFC standard gillnet, each mesh size given equal weight.

The changes in relative abundance and distribution of pink salmon are considered below by region.

Okhotsk Sea.

Information on the distribution and relative abundance of pink salmon in this region is based on limited sampling, mainly in waters adjacent to the Kuril Islands and off the southwest coast of Kamchatka in July of 1959 and 1960. In 1959, pink salmon were very abundant, relative abundance indices ranging from 34 to 87. During mid-July, abundance levels increased from south to north. In area E5052, abundance levels increased through the latter half of the month. In 1960, in the southern waters, pink salmon were not as numerous as in 1959.

Landbased Fishery Region.

Information on distribution of pink salmon is extemely limited for this region. In May 1955, in area E7044, the abundance level was high (CPUE, 32) and decreased northward. In May 1956, fishing east of Longitude 160°E and southward to about Latitude 40°N indicated that pink salmon were present in relatively small numbers to at least Latitude 42°N and that their numbers increased eastward. In June 1957, very high abundance levels (CPUE, 121–194) were recorded off the central and northern Kuril Islands. In mid-July 1958, relative abundance off the central Kurils was high (CPUE, 26–43) and tended to increase offshore.

Southeast Kamchatka-Southwest Aleutian.

Fishing by research vessels in this region was fairly intensive but coverage varied between years.

In 1955, pink salmon were moderately abundant in area E7046 (CPUE, 16) during May, in area E6552 (CPUE, 11) in mid-July, and relatively scarce southeast of Kamchatka in August. They were apparently absent south of Attu Island in September.

In 1956, in area E7048, no pink salmon were caught in May, although some did occur in the landbased region to the south. Through June, south of Attu Island, abundance levels were low but increased to the south (Appendix Table C). Through July and August, southeast of Kamchatka, pink salmon were usually present in relatively low numbers.

In 1957, in May, southwest of the Aleutians, pink salmon were low in abundance. June fishing showed two large centers of concentration, one located directly south of Kamchatka and the other southwest of the western Aleutians. Pink salmon abundance in the latter area increased markedly through June. During July, pink salmon decreased generally in abundance and in August, according to very limited fishing, were very scarce.

In 1958, limited and scattered fishing showed pink salmon in May to be absent directly south of Kamchatka and present only in low numbers to the southeast of that peninsula. During June, and thereafter into August, abundance levels continued to be low.

In 1959 south of Attu Island, pink salmon appeared to be absent in May and present only in low numbers

in June. Fishing in August in the northern part of the region indicated pink salmon to be present only in low numbers north of Latitude 54°N.

In 1960, during June, abundance levels of pink salmon east of Longitude 165°E ranged from low to medium, with the highest index occurring in area E6552. Thereafter, fishing in northern waters indicated low levels of abundance. In August, in some areas, pink salmon were not caught.

In summary, sampling in this region has varied considerably in intensity and coverage. In all years but 1957, pink salmon were either scarce or absent in May, low or moderately abundant in June and decreased in abundance in July and August, frequently being absent in the latter month. In June 1957, pink salmon were very abundant south of Kamchatka and southwest of the Aleutians. Their numbers declined rapidly in July.

Aleutian Region.

Coverage in this region through the season in most years has been more extensive than in most other regions.

In 1955, fishing in May occurred only in area E7548. Pink salmon abundance levels were low. More extensive fishing in June showed that abundance levels ranged from low to very high. The highest abundance levels occurred in the central part of the region north of Latitude 48°N. No fishing was carried out in July, but in August and September, pink salmon were not caught, even though operations extended as far south as Latitude 45°N.

In 1956, during May and early June, abundance levels were medium in southern waters and decreased to the north and northwest. Later in June, pink salmon were present in low levels of abundance throughout most of the region. None was caught in sets made immediately south of Adak Island and along Latitude 43°N. Following June, except for a small catch south of Adak Island in late August, pink salmon were entirely absent.

In 1957, as in 1955, pink salmon were usually very abundant in waters adjacent to the Aleutians during May and June. Abundance indices ranged from 42 (area W7550) during May to 64 (area E7550) during early June. Following early June, abundance levels declined. After late July, pink salmon were either absent or very scarce in the region.

In 1958, abundance levels from May through early July were usually low. In some areas, pink salmon were not caught. In August, in the eastern part of the region, they were virtually absent.

Table 28. Average relative abundance indices for pink salmon (research vessel data) in the Aleutian region north of Latitude 46°N, by 10-day period, 1955–1960. The "plus" sign indicates pink salmon present in very low numbers.

Period	1955	1956	1957	1958	1959	1960
May	1	1	42	3	3	5
Early June	33	7	56	0	9	4
Mid-June	14	4	33	0	10	1
Late June	—	0	19	0	—	1
Early July	—	—	2	1	20	+
Mid-July	—	—	—	1	0	3
Late July	—	—	0	—	2	8
Early August	2	0	+	+	+	0
Mid-August	0	0	+	+	0	+
Late August	0	+	+	—	—	—
September	0	0	—	—	—	—

In 1959, from May through July, pink salmon were more numerous in the eastern than in the western part of the region. In area W7052, abundance indices increased from low in May to high in early July. Limited fishing along Latitude 49°N in the eastern areas in August failed to catch any pink salmon.

In 1960, during May and early June, when fishing was conducted in the eastern areas mainly north of Latitude 46°N, abundance levels were uniformly low. Abundance levels in July ranged from low to medium, with the highest levels occurring in area W7050.

To summarize, south of the Aleutian Islands between Longitudes 175°E and 165°W, pink salmon varied in their distribution and abundance both seasonally and annually. (This is clearly evident from Table 28, which gives the average abundance levels by 10-day period from 1955 to 1960.) Abundance levels were considerably higher in the odd-numbered years than in the even-numbered years. In 1955 and 1957, peak abundance levels occurred between May and mid-June and then decreased rapidly. In 1959, the peak period was in early July. In even-numbered years, this seasonal change in relative numbers was not quite so apparent. Considering all years, the southern limit for pink salmon in May would appear to be between Latitudes 42°N and 40°N; in June, north of Latitude 44°N.

Western Bering Sea.

Fishing by research vessels in this region was carried out mainly during July and August. Information for May and June is available only for 1958, 1959 and 1960.

In 1955, during mid-July, abundance levels were high in the central area and decreased to the south and east. Fishing in August off northeast Kamchatka indicated that pink salmon were present only south of Latitude 60°N and in low levels of abundance.

In 1956, fishing took place mainly after mid-July. Pink salmon were present south of Latitude 58°N in low numbers during late July and early August.

In 1957, during mid-July in area E6558, abundance levels were very high (CPUE, 130).

In 1958, in May and June, in all areas fished but E6558, abundance levels were generally low. In area E6558, abundance levels increased through June from low to very high. After June, pink salmon, still in low numbers, were present mainly in northern waters.

In 1959, fishing was mainly carried out in August. Abundance levels were uniformly low but the relative numbers of pink salmon increased northward (Appendix Table C).

In 1960, abundance levels in June in the southeast part of the region were low. To the north and west, abundance levels were medium. In July and August, pink salmon were relatively scarce.

Thus, during May and early June, pink salmon were relatively most abundant in the southeast areas of the region. Through the season, the areas of concentration shifted northwestward and peak numbers usually occurred in July. Abundance levels generally declined thereafter. Pink salmon would appear to be relatively more numerous in odd-numbered than in even-numbered years.

Central Bering Sea.

Coverage in this region varied in different years, but in general was rather extensive, particularly south of Latitude 58°N during May through July.

In 1955, fishing in May in area 8052 failed to catch any pink salmon. In late June in area 8054, abundance levels were high. In July, pink salmon were present in from low to medium numbers in the southwest areas and, except in area W7560 where they were present in low numbers, were absent in areas to the north and east.

In 1956, rather extensive fishing in June showed abundance levels to be very low in almost all areas. Pink salmon were virtually absent in the eastern areas after June.

TABLE 29. Average relative abundance indices for pink salmon (research vessel data) in the Central Bering Sea region south of Latitude 58°N, by 10-day period, 1955–1960. The " plus " sign indicates pink salmon present in very low numbers.

Period	1955	1956	1957	1958	1959	1960
May	0	—	—	2	—	—
Early June	—	3	30	2	3	3
Mid-June	0	1	53	3	7	3
Late June	6	+	127	2	38	4
Early July	19	+	6	+	5	+
Mid-July	4	0	3	+	38	—
Late July	+	0	+	1	—	—
Early August	—	0	0	0	—	—
Mid-August	—	—	+	—	—	—
Late August	—	—	0	—	—	—
September	—	0	-	—	—	—

In 1957, in most areas fished in June, pink salmon were very abundant. In area 8052, abundance indices ranged from 61 in early June to 244 in late June. After June, abundance levels declined rapidly, indicating that pink salmon were actively evacuating the region. In July and August, pink salmon were present mainly in the western areas.

In 1958, scattered fishing showed that pink salmon were low in abundance from May through July. None was caught in the southeast areas in August.

In 1959, pink salmon were relatively very abundant in this region in June. The highest abundance value was recorded for area 8058 (203). The rapidity with which abundance levels changed through the season is indicated by areas E7556, E7552 and E7558. Abundance levels tended to be higher in the western than in the eastern areas.

In 1960, fishing through June south of Latitude 58°N indicated low abundance levels of pink salmon.

In summary, in the Central Bering Sea region, pink salmon were much more abundant in the odd-numbered years than in the even-numbered years. Table 29, which gives the average 10-day abundance values for the region south of Latitude 58°N for each year from 1955 to 1960, clearly shows this tendency. This tendency was similar to that noted for the Aleutian region. Further, the peak periods of abundance, especially in the odd-numbered years, differed annually. Maximal abundance levels in 1955 occurred during late June and early July; in 1957 in late June; in 1959 during late June to mid-July. In the odd-numbered years, abundance levels declined rapidly following the peak periods of abundance, the highest

levels occurring in the western and northwestern areas.

Eastern Bering Sea.

Fishing in this region in the different years in June has shown pink salmon abundance levels annually to be relatively low. By August, according to some years (1956, 1957), they were virtually absent.

Western Gulf of Alaska.

Coverage in this region between years has varied to a great extent. Fishing in April (1959) south of Kodiak Island and in May (1956) at widely scattered locations failed to catch pink salmon. In June, according to rather limited fishing north of Latitude 50°N, pink salmon were present in low numbers. In 1959, however, in the southwest areas, medium abundance levels were encountered. Through July, as far south as Latitude 50°N, abundance levels were usually low, but in some years (1956, 1959) medium levels were noted. After July, even though fishing extended southward to Latitude 48°N, pink salmon in different years were present only in areas close to the Alaska Peninsula. During this time of year relative abundance levels were low.

Central Gulf of Alaska.

Coverage of this region in all years was rather sparse, except for the period July through September in 1956. During May and June in all years fished, abundance levels were low. In July, according to fishing in 1956, abundance levels, while ranging from nil to medium, were higher in northern than in southern waters. The southern limit of pink salmon would appear to be between Latitudes 52°N and 50°N. By late August, pink salmon were no longer caught in the region.

Coastal Gulf of Alaska.

Considering all years together, fishing extended from Latitude 59°N southward to Latitude 42°N. Pink salmon abundance levels were low in May and June, reached a peak in July and early August and then declined. In May and June, the southern limit of catches was Latitude 46°N; in August, Latitude 52°N.

Monthly Distribution Pattern.

By considering information on the regional distribution of pink salmon, a monthly distribution pattern for the species in the North Pacific and the Bering Sea can be evolved.

In April, south of Kodiak Island, the only area fished in this month, pink salmon would appear to be absent.

In May, pink salmon occur in relatively low numbers continuously across the North Pacific. The southern limit in the western Pacific would appear to be between Latitude 42°N and 40°N (1956); in the eastern Pacific, at about Latitude 46°N (1957). Their presence in the extreme northerly waters in both the western and eastern sectors of the North Pacific is not annually consistent. In some years (1958), at least by late May, they may also occur in the southern part of the central Bering Sea.

In June, pink salmon in varying levels of abundance occur throughout the North Pacific and in almost all the areas fished in the Bering Sea as far north as Latitude 60°N.

During July, pink salmon are still widespread across the North Pacific and the Bering Sea in the early part of the month. Thereafter their numbers in the central regions decline as they migrate shoreward. The southern limit of catches is about Latitude 46°N in the western Pacific; about Latitude 50°N in the eastern Pacific.

By August, pink salmon have virtually evacuated the high seas areas and are present in waters approaching various coastal areas. Pink salmon present in the Aleutian region presumably are local populations.

Distribution of Odd-Year and Even-Year Pink Salmon.

Considering odd-numbered years and even-numbered years separately, certain general features regarding distribution and relative abundance in even-year and odd-year pink salmon are apparent. This type of consideration would appear reasonable since, for all practical purposes, pink salmon can be considered to mature in their second year, and further, research vessels caught maturing pink salmon only.

The distribution pattern of pink salmon of the same cycle was basically similar. Some differences and similarities between odd and even-year cycles were noted, however, the most outstanding difference occurring during the early months in each year. Odd-year pink salmon in June were extremely abundant in the North Pacific as far east as the eastern Aleutian Islands, and in the central Bering Sea. Even-year pink salmon, in contrast, were usually present in these regions only in relatively low numbers.

The distribution pattern for odd-year and even-year pink salmon was rather similar in waters off the tip of the Kamchatka Peninsula and along the Kuril Islands. According to limited fishing, pink salmon appeared to be very abundant in June and July.

They were also present during the same months in from moderate to high numbers in the western Bering Sea in both odd- and even-numbered years. Abundance levels usually were higher in odd-numbered years.

In the Gulf of Alaska, mainly because of limited fishing, the distribution pattern shown for odd-year and even-year pink salmon in Appendix Figure B-3 is not too clearly defined. Data in Appendix Table C do show, however, that, during the early part of the season especially, pink salmon were more numerous in even-numbered years in northern areas; in odd-numbered years in central and southern areas. Manzer and Shepard (1962) also pointed this out when considering data collected by Canadian research vessels only during the period 1956–1959 and indicated that these odd- and even-numbered year differences in distribution were related to the relative sizes of stocks originating in various regions bordering the Gulf of Alaska. In each year, the southern limit shifted northward monthly; in July, the species migrated from the high seas towards the coastal areas, where in some years pink salmon were abundant.

Within odd-numbered and even-numbered year cycles, abundance levels fluctuated annually. Fluctuations were particularly apparent in the odd-year pink salmon. The three odd-numbered years considered in this report, in order of highest abundance level, were 1957, 1959 and 1955. Part of these annual fluctuations in abundance was undoubtedly due to sampling variation, but some must have been due to real differences in the relative numbers of pink salmon.

There is some suggestion that the timing of the peak abundance levels within each year also varied. Referring to Tables 28 and 29, it would appear that peak abundance levels in both the Central Bering Sea and the Aleutian regions were later in 1959 than in 1957.

2. *Mothership Operations*

(a) Catch.

The monthly catch of pink salmon by the Japanese mothership fishery since 1952 in the North Pacific Ocean, Bering Sea and Okhotsk Sea is given in Table 30. The catches of pink salmon by statistical area and 10-day period during the years 1952 to 1960 are illustrated in Appendix Figure C-3, which is based on data from Appendix Table D.

North Pacific. Fishing effort and catches of pink salmon in the North Pacific were larger than in either the Okhotsk Sea or the Bering Sea.

The annual catch increased from 0.7 million fish in 1952 to 14.2 million fish in 1955. This increase in catch was mainly due to annual increases in fishing effort. In 1956, in spite of further increased fishing effort, the catch dropped to 11.8 million. The drop was due primarily to prohibition of fishing west of Longitude 170°E prior to mid-July, a regulation arising from Japan-Soviet treaty talks in that year. The bulk of the total catch was made southeast of the Kamchatka Peninsula. In 1957, a record high catch of 17.4 million pink salmon was made. Since fishing effort in that year was lower than in 1956, pink salmon must have been extremely abundant in 1957. In 1958, a total of 13.2 million pink salmon was caught. Two factors may account for this large catch. First, with no fishing being conducted in the Bering Sea, almost all the mothership fleets fished off the southeast coast of the Kamchatka Peninsula. Second, because of poor fishing generally, fishing was permitted until early August, resulting in a more intensive fishery for pink salmon than for the other species during the latter part of the season. In 1959 and in 1960, the catches dropped sharply. The catch in 1960 amounted to

Table 30. Pink salmon catches (in thousands of fish) by Japanese mothership operations, 1952–1960.

	North Pacific					Bering Sea			Okhotsk Sea				
Year	May	June	July	Aug.	Total	June	July	Total	June	July	Aug.	Total	Total
1952	1	50	602	46	699	—	—	—	—	—	—	—	699
1953	+	167	2,263	633	3,063	—	—	—	—	—	—	—	3,063
1954	5	209	3,751	1,831	5,796	—	—	—	—	—	—	—	5,796
1955	74	4,521	7,777	1,870	14,242	—	—	—	1,351	5,683	1,580	8,614	22,856
1956	50	352	10,078	1,353	11,833	31	8	39	570	4,129	668	5,367	17,239
1957	332	5,948	11,078	—	17,358	2,372	1,317	3,689	2,162	4,672	—	6,834	27,881
1958	69	3,678	8,826	628	13,201	—	—	—	1,050	1,058	240	2,348	15,549
1959	216	7,732	2,364	—	10,312	184	8,362	8,546	—	—	—	—	18,858
1960	60	511	301	8	880	634	375	1,009	—	—	—	—	1,889

only 0.9 million fish. This catch was only slightly larger than the catch in 1952 when fishing effort was minimal and considerably lower than it was in 1960 (see Tables 3 and 30).

In each year but 1959 and 1960, the catches in July exceeded those made in other months. In 1959 and 1960, largest catches were made in June.

Bering Sea. The annual catches in this region fluctuated violently, exhibiting high numbers of pink salmon in odd-numbered years and lower numbers in even-numbered years. The largest catch occurred in 1959 (8.5 million fish). In 1960, an " off-cycle " year for pink salmon in this region, just over one million pink salmon were caught. This number is in marked contrast to the catch in 1956 (39,000 fish) when fishing effort was very much higher. No fishing occurred in 1958, hence no catches.

The fishing pattern varied greatly from year to year. Fishing began from mid-June to late June and lasted until mid or late July.

In 1956, fishing was conducted in waters south of Latitude 60°N and west of Longitude 175°W during mid-June through late July. The total catch of pink salmon amounted to 39,000 fish.

In 1957, most of the mothership fleets in this region operated between Longitudes 175°E and 175°W and south of Latitude 60°N during mid and late June. Effort in these waters was directed mainly to catching sockeye salmon, but even at that large numbers of pink salmon also were caught, reflecting their high abundance level. In July, two mothership fleets fished the region, mainly for pink salmon. The statistical areas producing the highest catch in each 10-day period were as follows: mid-June, E7552 (428,000); late June, 8054 (532,000); early July, 8056 (267,000); mid-July, E6556 (211,000).

In 1959, fishing was carried out west of Longitude 180° and mainly between Latitudes 56°N and 60°N during July, essentially for pink salmon. (Pink salmon made up 76.2% of the total number of salmon caught in this region.)

In 1960, the fishing pattern was similar to that in 1957. Motherships operated between Longitudes 165°E and 175°W during mid and late June and fished principally for sockeye salmon. Since 1960 was an " off-cycle " year for pink salmon, catches were generally very small. Concentrations of pink salmon, however, were encountered west of Longitude 170°E from late June to mid-July. In late June, 109,000 pink salmon were caught in area E7058; in early July, 164,000 in area E6558 and 166,000 in area E6556.

Okhotsk Sea. Commercial fishing in this region was conducted from 1955 to 1958, two mothership fleets operating in 1955, 1956 and 1957, and only one in 1958.

In spite of comparatively small fishing effort, the total pink salmon catches were large. A record total catch of 8.6 million pink salmon was made in 1955. This number equalled about 60% of the total number of pink salmon caught in the North Pacific in the same year. Considering individual years, catches tended to be greater in odd-numbered years than in even-numbered years. The small catch in 1958 was due in part to reduced fishing effort.

Fishing was mainly carried out from late June into early August, in areas E5050 and E5052. The peak fishing period advanced with each successive year. Further, the catch during each peak period decreased annually.

In summary, there are three productive areas for pink salmon, according to mothership catches. One of these areas is off the west coast of the Kamchatka Peninsula and the second is off the southeast coast of the Kamchatka Peninsula and the northern Kuril Islands. These two areas were productive in both odd- and even-numbered years. In 1960, however, catches were exceptionally low. The third important fishing area, but only in odd-numbered years, lies immediately south of the Aleutian Chain and extends into the Bering Sea as far north as areas E7558 and 8058.

The pink salmon has been one of the most important species in the mothership fishery. The productive Okhotsk Sea fishing areas were closed to fishing in 1959 and thereafter. The southwest areas of the North Pacific lost their value as important pink salmon areas when abundance levels dropped markedly in 1960. In the Bering Sea, the pink salmon has been abundant along with the sockeye salmon, which has a higher commercial value.

(b) Relative Abundance.

Relative abundance indices (catch per tan values) computed from the mothership fishery statistics are useful not only for determining annual and monthly variations in the relative numbers of salmon, but also for showing centers and movements of salmon concentrations. To properly evaluate changes in the abundance levels of pink salmon, the efficiency of commerical gillnets must be considered.

TABLE 31. Annual pink salmon catch per tan values in mothership operations by major fishing region. The "plus" sign represents a value less than 0.05.

Year	North Pacific	Bering Sea	Okhotsk Sea
1952	1.5	—	—
1953	2.3	—	—
1954	1.8	—	—
1955	2.0	—	12.4
1956	1.6	+	11.4
1957	3.3	2.9	12.7
1958	1.5	—	6.0
1959	1.7	6.1	—
1960	0.2	0.6	—

It was pointed out in Section V that commercial gillnets of 4.8" mesh used in the mothership fishery were too large to catch pink salmon efficiently. Seasonal and annual changes in efficiency of the 4.8" mesh gillnets were noted (Table 11). The efficiency varied within and between years and between areas containing pink salmon of different sizes. The efficiency of the 4.8" mesh generally increased as the season progressed.

In the early years (1952, 1953 and 1954) of the mothership fishery, an even larger mesh size (5.1") was used. The 5.1" mesh was even less efficient for taking pink salmon than the 4.8" mesh. Thus, when comparing relative abundance indices for pink salmon, mesh size efficiency must be kept in mind.

The annual catch per tan of pink salmon in each major region is listed in Table 31.

The catch per tan indices for pink salmon by statistical area and 10-day period for the years 1952–1960 are shown in Appendix Figure D-3.

North Pacific. The average annual catch per tan values for pink salmon from 1952 to 1960 ranged from a low of 0.2 in 1960 to a high of 3.3 in 1957. Odd-year pink salmon were the dominant cycle. Because larger meshed gillnets were used in 1952, 1953 and 1954 than in subsequent years, the indices for these years are comparatively low. In 1960, compared with other years, pink salmon were very scarce.

The arrival of pink salmon in the North Pacific region fished by motherships was much the same in both odd-numbered and even-numbered years. In general, pink salmon were scarce in May, but when caught were mainly taken in southern and eastern areas. Through the season they occurred further north and their numbers increased. Larger numbers first appeared to the southward, indicating that pink salmon were moving in from this general direction.

TABLE 32. Periods and areas of peak abundance levels of pink salmon in the northwest Pacific in even-numbered and odd-numbered years.

Year	Period	Maximum catch per tan value	Area
1952	early August	8.5	E 6050
1954	mid-July	8.9	E 5548
1956	mid-July	31.0	E 5548
1958	mid-June	6.1	E 5548
1958	mid-July	6.0	E 5548
1958	early August	6.6	E 5548
1960	mid-June	1.9	E 6048
1953	late July	9.3	E 6052
1955	mid-July	9.7	E 5548
1957	early July	16.0	E 5550
1957	early July	16.0	E 6048
1959	late June	5.3	E 7048

The distribution patterns of even-year and odd-year pink salmon differed (Appendix Figure D-3). The major portion of even-year pink salmon occurred in areas west of Longitude 165°E, with the greatest concentration occurring in waters adjacent to the northern Kurils and southeast Kamchatka. Odd-year pink salmon were present in larger numbers over a much wider area, extending eastward into waters south of the Aleutians. There was, however, a tendency for pink salmon of both cycle years, for corresponding time periods, to decline in relative numbers eastward from the northern Kurils and southeast Kamchatka. Pink salmon in 1959, in contrast to other odd-numbered years as well as even-numbered years, appeared to be relatively more numerous in the offshore areas.

The peak period of abundance advanced with each successive year (Table 32). Peak density levels occurred during early August in 1952, late July in 1953, mid-July in 1954, 1955 and 1956, early July in 1957, mid-June to early August in 1958, late June in 1959 and mid-June in 1960. It is possible that the apparent late peaking of abundance levels in 1952 and 1953 to some extent reflects the usage in those years of larger meshed gillnets than were used in later years, their efficiency not being fully felt until later in the season when pink salmon were larger in size. Although pink salmon were more numerous off the northern Kurils and southeast Kamchatka than they were to the eastward, it was apparent that in both cycle years the areas of peak abundance were not necessarily the same in all years.

Bering Sea. Relative abundance levels of pink salmon in the Bering Sea fluctuated violently from year to year. In 1956, catch per tan values from mid-

June to late July were very low throughout the region.

In 1957, very high abundance levels were observed in a number of areas throughout the region from mid-June to mid-July. The areas of concentration in late June were E7556 (catch per tan, 7); in early July, E7556 (catch per tan, 12) and E7056 (catch per tan, 11), and in mid-July in E6556 (catch per tan, 9) and E6558 (catch per tan, 9). A westward movement is indicated by these values.

In 1958, according to catch data for research vessels fishing with large quantities of commercial gear, pink salmon were not particularly abundant in the Bering Sea. Throughout the season, relative abundance levels were generally low. In area E6558, where highest values for the season were recorded, relative abundance levels increased through June. By August they were again low.

In 1959, fishing was first conducted in area E7052 during early June. Pink salmon were relatively very low in numbers. By mid-June and until fishing stopped in mid-July they were considerably more numerous. Further to the north, between Latitudes 56°N and 60°N, and west of Longitude 180°, in July, pink salmon were very abundant. Highest levels were reached in early July and declined with each succeeding 10-day fishing period. Pink salmon in area E7560 in late July were relatively much less abundant than in areas E7058 and E7558.

In 1960, abundance levels of pink salmon, although higher than in 1956, were low in all areas east of Longitude 170°E during the period fished, mid-June to early July. In areas E6556 and E6558, pink salmon were relatively much more numerous in late June and early July than elsewhere.

Okhotsk Sea. Pink salmon were abundant in the Okhotsk Sea in all years from 1955 to 1958. The annual average catch per tan value was 12.4 in 1955, 11.5 in 1956, 12.7 in 1957 and 6.0 in 1958. In 1956, there was no fishing in early and mid-June, a period when pink salmon densities are usually low. Had fishing been conducted during the early periods, the average values for the entire season in 1956 presumably would have been much lower than in 1955 and 1957. Considering this feature, pink salmon would appear to be more numerous in odd-numbered than in even-numbered years.

Figure 28, which shows the average catch per tan index for each 10-day period for the years 1955 through 1958, indicates that pink salmon were usually most numerous in July. In 1958, however, the peak period occurred in late June with the suggestion of a secondary peak in mid-July.

In summary, from 1952 to 1960, odd-year pink salmon were relatively more abundant and had a somewhat different distribution pattern than even-year pink salmon in the mothership fishing grounds. Therefore, information on these two cycles, as derived from mothership operations, is summarized separately.

In even-numbered years, in the North Pacific and the Bering Sea, pink salmon were abundant only in areas off southeast Kamchatka and the northern Kuril Islands. Highest abundance values occurred in areas off the southern tip of the Kamchatka Peninsula. The period of peak abundance appeared to be earlier in the season in later years than in earlier years. In 1960, in the North Pacific, the abundance levels were considerably lower southeast of Kamchatka than in previous even-numbered years. Also, in the Western Bering Sea region, pink salmon during late June and early July were particularly abundant for an even-numbered year.

In odd-numbered years, off southeast Kamchatka, pink salmon abundance levels were equal to or greater than those in even numbered years. In contrast to

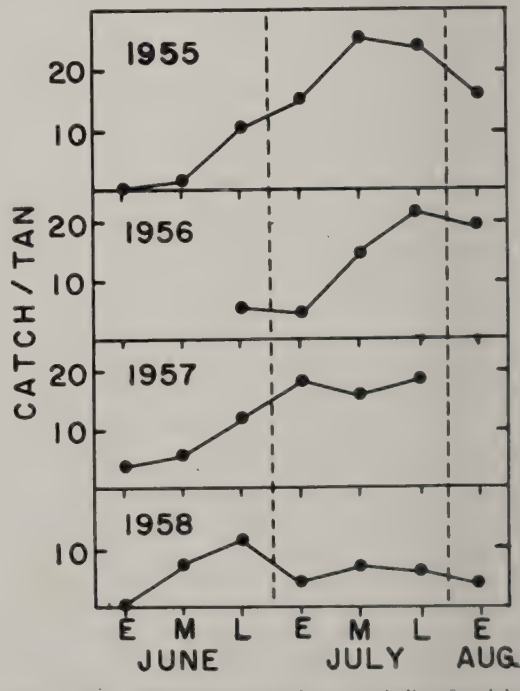

FIGURE 28. Changes in the catch per tan indices for pink salmon in the Okhotsk Sea, 1955–1958.

even-numbered years, pink salmon were also very abundant south of the Aleutian and Komandorski Islands and into the Bering Sea. In 1957 and 1959, when intensive fisheries were conducted in the Bering Sea, highest relative abundance values were recorded earlier in the south than in the north. Along the Aleutian Chain, maximum values were recorded in mid and late June. In the Bering Sea, north of Latitude 56°N, maximum values were recorded during early and mid-July. Very high levels of abundance were recorded in the northwest areas of the Bering Sea. Along the Aleutian Islands, pink salmon were more abundant in 1957 than in 1959.

In the Okhotsk Sea, pink salmon were relatively more abundant than in either the North Pacific or Bering Sea during the four years of fishing (1955–1958). Abundance levels were higher in odd-numbered than in even-numbered years, and were especially low in 1958.

3. *Landbased Region Operations*

Information on distribution and relative abundance of pink salmon in this region is available only from Japanese research and training vessels fishing with commercial gillnets (4.5″ mesh) authorized for the region, for the years 1956 to 1960. The catch per tan (180 feet) values by statistical area and 10-day period are tabulated in Appendix Table E and plotted in Appendix Figure D-3, along with mothership data.

As described in Section V, the 4.5″ mesh gillnets fished in the landbased region have a higher mesh size efficiency for pink salmon than the 4.8″ mesh gillnets used in mothership operations. Mesh size efficiency was defined as the ratio of the catch in a gillnet of any given mesh size to the possible catch by a gillnet having a mesh size of optimum efficiency. Excluding very low values for the mothership fishery in the Okhotsk Sea in 1958, the mesh size efficiency in the mothership fishery for June and July of all years averaged 0.45, while that for the landbased fishery averaged 0.68 (from Tables 11 and 12). The ratio of the former to the latter is 0.45 to 0.68. According to these values, gillnets used in the landbased region are approximately 50% more efficient for catching pink salmon than are those used in the mothership fishery. This greater efficiency of the gillnets used in the landbased fishery should be kept in mind when considering relative abundance indices for this region.

In 1956 in May, between Latitudes 42°N and 48°N and west of Longitude 165°E, pink salmon abundance levels were low (catch per tan less than 1.0). In area E4542, east of Hokkaido, in June, abundance levels increased through the month, indicating that pink salmon were becoming more numerous. Their numbers in this area declined following late June. Pink salmon in July were relatively more abundant northward. Highest catch per tan values (23) were recorded in area E5546 during late July. The average catch of pink salmon per tan in 1956 was 4.5 fish.

In 1957 during May, areas west of Longitude 165°E and between Latitudes 42°N and 46°N were fished. Pink salmon were relatively most abundant (catch per tan, 10) in area E4544. Their numbers declined east and south from this area. During June and July, as fishing gradually shifted toward southeast Kamchatka, abundance levels increased. During mid-July, the season's highest pink salmon density levels were encountered in areas E5046 and E5546 (catch per tan, 10 and 14, respectively). Late July indices in these areas indicated a sharp drop in pink salmon abundance. The seasonal average catch of pink salmon per tan in 1957 was similar to that in 1956, 4.8 as compared with 4.5.

In 1958, research vessels operated more widely than in either 1956 or 1957. Fishing began in May in areas off northern Japan and the southern Kurils and extended offshore into area E6544. As the season progressed, operations gradually shifted northward. By July, areas west of Longitude 170°E and between Latitudes 44°N and 48°N were fished. During the course of these operations, pink salmon density levels were highest off northern Japan in May and June (catch per tan, 8.9 and 4.9, respectively) and progressively decreased offshore. In July, abundance levels generally were higher, especially during the early part of the month. By the end of the month, however, abundance levels were relatively low, with the highest levels occurring in areas adjacent to the Kuril Islands. On the average, pink salmon abundance levels were considerably lower in 1958 than in either 1956 or 1957.

In 1959, fishing in May was conducted some distance offshore from northern Japan and the southern Kuril Islands (mainly in areas E5542 and E6044). Pink salmon through May would appear to be concentrated to the southeast as relative abundance indices progressively increased offshore. In June, when areas to the west also were fished, pink salmon were relatively abundant in two areas, E4540 (catch per tan, 31) and E6044 (catch per tan, 12). In July, off the central Kurils, pink salmon were generally present, but were relatively most numerous in area E5546, immediately northwest of area E6044. During August, abundance levels generally had declined to very low levels, es-

pecially offshore. Average seasonal abundance indices in 1959 were the highest (catch per tan, 5.2) of the five years of experimental fishing in the landbased region.

In 1960, pink salmon were present generally, but in very low numbers (seasonal average catch per tan, 1.4). In late May, when fishing was rather extensive, relative abundance levels increased offshore from northern Japan. In June, maximal densities occurred closer to Japan and the Kurils than in May, indicating that pink salmon had approached these areas. In July, pink salmon were relatively most abundant to the north.

To summarize, research vessels operating with 4.5″ mesh gillnets provided information on pink salmon distribution in the landbased fishery region during May into August. Although coverage of the region varied in space and time during the years of study (1956–1960), a basic distribution pattern was evident. In May, pink salmon occurred extensively off northern Japan as far west as about Longitude 170°E, the westward limit of fishing. Their numbers tended to increase southward suggesting that the area of concentration was in this direction. In certain years (1957, 1958, 1960), maximal densities occurred in areas adjacent to or relatively close to northern Japan and the southern Kurils. Through June, abundance levels generally increased and, except for a slight northward shift in position of the areas of maximal densities, pink salmon were relatively most numerous in waters adjacent to the Kurils. An exception to this tendency occurred in 1959, when pink salmon were also relatively abundant considerably offshore (area E6044—catch per tan, 12). In July, the northward shift in areas of concentration noted in June continued. Concomitantly, relative abundance levels in areas to the south progressively declined. Generally, pink salmon were relatively scarce in August, but their numbers increased shoreward.

According to annual average relative abundance indices, pink salmon tended to be more abundant in odd-numbered than in even-numbered years.

4. *Summary*

Catches by INPFC research vessels, mothership fisheries and research and training vessels operating in the landbased region have shown pink salmon in the North Pacific and the adjacent seas to vary annually in their relative numbers and distribution. The basic monthly distribution pattern of pink salmon from May through August in both odd- and even-numbered years, derived from all sources of data, are schematically illustrated in Figure 29.

The monthly occurrence pattern was somewhat similar in odd- and even-numbered years. In general, in May, pink salmon occurred in a continuous wide band across the North Pacific. The width of this band in the western Pacific extended roughly between northern Honshu in the south to about Latitude 52°N in the north. Approximate corresponding southern and northern limits in the eastern Pacific were Latitudes 45°N and 55°N, respectively. The void area in the eastern Pacific appeared to extend further south in the region south of the Alaska Peninsula in the even-numbered years. In June, pink salmon did not occur as far south as in May, and in addition were present in the northern Gulf of Alaska and in the Bering Sea as far north as fishing was conducted (Latitude 60°N). During July and August, the progressive constriction of waters of the central Bering Sea and the North Pacific where pink salmon occurred, and a further northward shift in the southern limit of pink salmon, indicated that they were evacuating the high seas areas. It is reasonable to think that pink salmon in the Aleutian areas during August represent local populations rather than late migrants to other areas.

Of the monthly northern and southern limits, those for May are perhaps the least certain. Coverage by fishing vessels was poorest during this month and, coupled with this, pink salmon, because of their small size, presumably were less catchable than later in the season. The northern limit in the even-numbered years in May was derived from catches made in 1958 and may not be typical of all years.

The distribution patterns of odd-year and even-year pink salmon differed even though the occurrence of fish belonging to these two cycles was reasonably similar in any given month, except possibly May. In odd-numbered years, especially in June, pink salmon were very abundant in the North Pacific from the Kurils eastward to the eastern Aleutians and into the central areas of the Bering Sea. They were considerably less numerous in the eastern areas of the Bering Sea, in southern waters of the central North Pacific and in the Gulf of Alaska. As pink salmon approached coastal areas in July, maximal densities occurred in areas adjacent to Kamchatka and in the Gulf of Alaska. In the latter region, while relatively abundant, they were less numerous than off Kamchatka. In August, with much of the coastward migration completed, pink salmon were most abundant in the eastern areas of the Okhotsk Sea.

In even-numbered years in June, pink salmon were concentrated in the western Pacific but, in contrast to the distribution pattern in odd-numbered years,

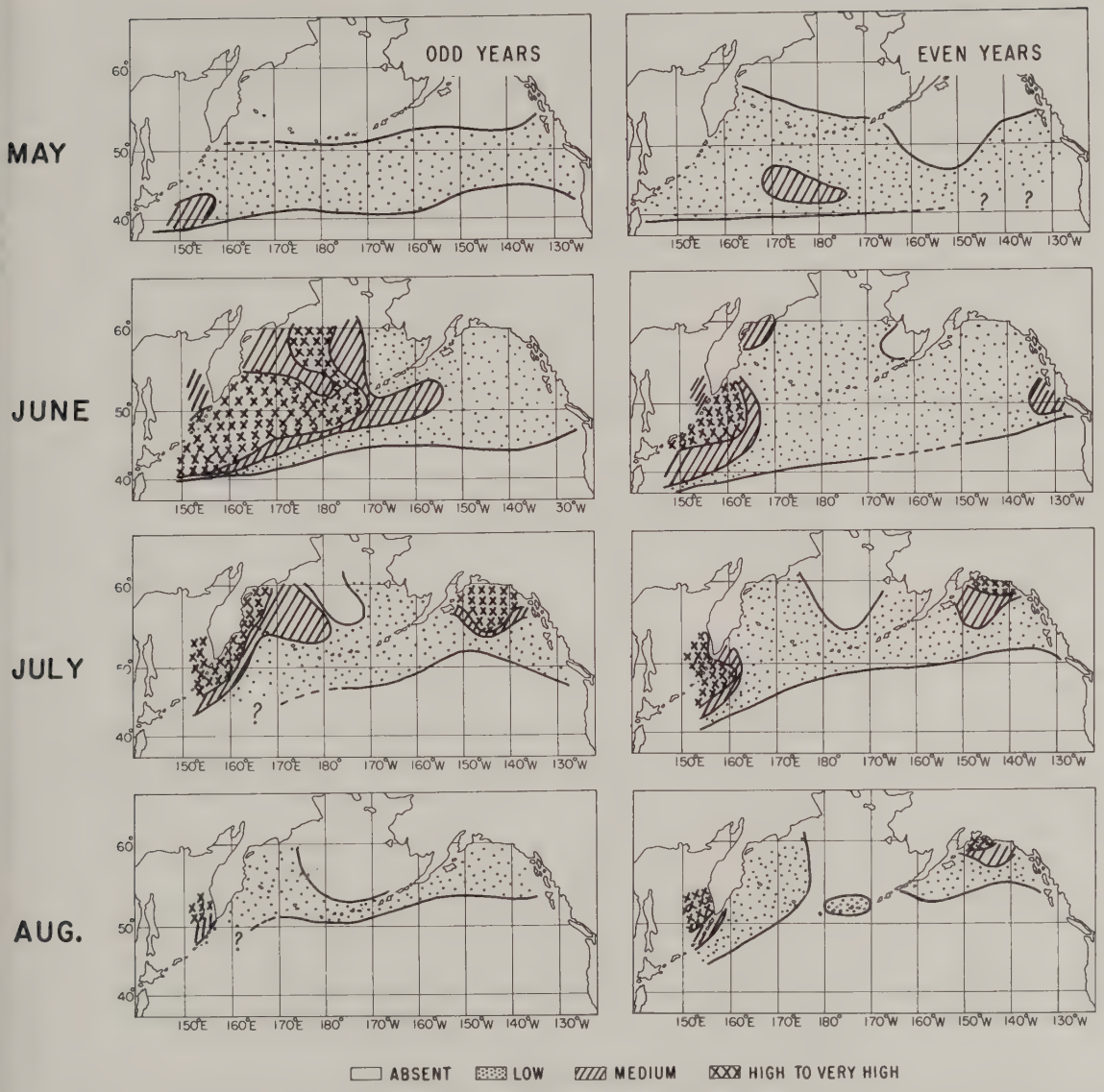

FIGURE 29. Schematic diagram showing distribution and relative abundance of pink salmon in odd- and even-numbered years, May through August.

this concentration did not extend eastward much beyond Longitude 170°E. Also differing from the distribution pattern of odd-year pink salmon, a minor area of concentration of even-year pink salmon was suggested for the southeast Gulf of Alaska. In July and August in even-numbered years, the main concentrations of pink salmon were located in areas south of Kamchatka and in the northern Gulf of Alaska. In the latter region in July, pink salmon were not as abundant as far south as in odd-numbered years.

A comparison of annual catch per unit of effort indices indicated that odd-year pink salmon were the dominant cycle in the western areas of the Pacific, the Bering Sea and the Okhotsk Sea. They were also numerous in even-numbered years in the western Pacific and the Okhotsk Sea. In the Gulf of Alaska, even-year pink salmon were the dominant cycle in the northern areas, odd-year pink salmon in the southern areas.

B. Length and Sex Ratio in Pink Salmon

Information on fork length and sex ratio in pink salmon caught in the mothership fishery and, by research vessels using commercial gillnets, in the landbased region is based on data given in Appendix Table G for the years 1957 to 1960, by month.

During these years, the mesh size of gillnets fished in the mothership fishery was predominantly 4.8″, while that in the landbased region was 4.5″. As shown in Section V, considerable bias can result from the selectivity of commercial gillnets on pink salmon. The 4.8″ mesh nets tend to select the larger pink salmon. This effect is especially pronounced early in the season when pink salmon are small. Accordingly, the length composition of the mothership catches has been adjusted by the mesh size efficiency values given in Table 11 in order to estimate the actual length composition of the population. The length composition data for pink salmon caught in the landbased region were treated similarly.

The estimated average lengths of pink salmon in the population for combined years are compared with those from the catch (Table 33). In May, the average length (in both males and females) in the catch was 3 to 4 cm larger than the estimated average length in the population in both the mothership and landbased operations. This difference in average lengths between catch and population decreased as the season progressed. In August, in the mothership fishery, the average length in the catch was only about 1 cm larger than the estimated average length. In August, in the landbased region, the mean length of the catch was about 1 cm smaller. The commercial mesh sizes were more suitable for the sizes of fish in the population in August than in May. By July and August, pink salmon had grown to a size more suitable for the commercial nets.

In both the mothership and landbased regions for the years 1957 through 1960 combined, male pink salmon were consistently larger than females, and each sex increased in average length through the season (Table 33). Pink salmon were smaller in the landbased region than in the mothership fishery in May

Table 33. Average fork lengths* (cm) of pink salmon in the mothership and landbased region catches and estimated average fork lengths in the available population.

(A) *By sex, by month, 1957–1960 combined*

			May	*June*	*July*	*August*
Mothership	in catch	female	45	46	48	50
		male	47	48	49	52
	in population	female	42	44	46	50
		male	44	45	47	51
Landbased	in catch	female	43	45	48	51
		male	50	46	48	51
	in population	female	39	43	47	52
		male	41	44	47	53

(B) *By month, by year, mothership only*

			May	*June*	*July*	*August*
North Pacific (& Bering Sea)	in catch	1957	46	47	47	—
		1958	48	47	49	51
		1959	48	48	48	—
		1960	47	47	49	52
	in population	1957	43	45	45	—
		1958	47	45	46	49
		1959	47	46	46	—
		1960	44	45	48	51
Okhotsk Sea	in catch	1957	—	47	47	—
		1958		46	48	50
	in population	1957	—	44	45	—
		1958		43	44	50

* Rounded values.

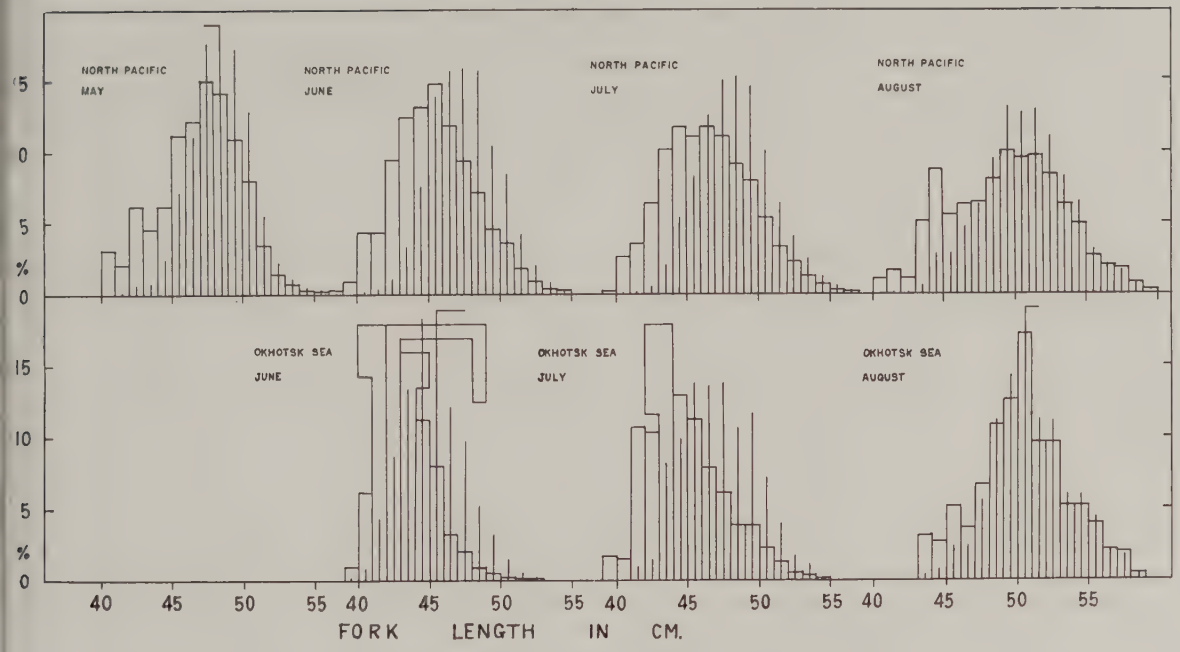

FIGURE 30. Fork length frequency distribution for pink salmon in mothership catches and estimated length frequency distribution (histograms) in the population, by month, in 1958.

and June; in July, they were approximately the same size in both fisheries; and in August, they were slightly larger in the landbased region than in the mothership fishery.

Figure 30 shows, for 1958 by month, the length frequency distributions (both sexes combined) of pink salmon in the mothership catch in the North Pacific and the Okhotsk Sea and the estimated length frequency distributions in the populations, adjusted for gillnet selectivity effects. In each region in each month, the actual catch consisted of larger fish than were estimated to be in the population.

Table 33 also gives, for each month in each of the years 1957 through 1960, the average lengths (sexes combined) of pink salmon in the mothership catch and the estimated average lengths in the population. Average lengths in the catch were always greater, again indicating selectivity effects.

In the North Pacific (including the Bering Sea) and in the Okhotsk Sea, lengths (sexes combined) of pink salmon increased as the season progressed from May to August. In 1958 and 1959, however, average lengths of pink salmon in the North Pacific were larger in May than in June (also larger than in May of 1957 and 1960). Fishing effort in May of 1959 and 1960 was relatively greater in the southwestern part of the North Pacific than in May of other years and also greater than in June of all years. Considering the distribution of fishing effort and the lengths of pink salmon, those fish in the southwestern part of the North Pacific appeared to be larger than those in areas to the northeast.

The average lengths of pink salmon in the Okhotsk Sea and the North Pacific (including the Bering Sea) in 1957 were similar (47 cm). In 1958, pink salmon caught in the western Pacific, on the average, were larger than those taken in the Okhotsk Sea.

The sex composition of pink salmon in commercial gillnet catches is also subject to bias caused by mesh selectivity; males are larger than females and therefore are more available to the gillnets. Sex ratios in the catch and estimated sex ratios in the population by month for combined years in the landbased region and the mothership fishery are shown in Table 34.

The sex ratio in the pink salmon catch and the estimated sex ratio in the population both showed a change in the percentage of males as the season progressed from May to August. In the early part of the season, males were highly predominant, being more so in the mothership catches than in the landbased

TABLE 34. Mesh size efficiency* of gillnets for pink salmon in the mothership and landbased regions, percentage of males in the catch and estimated percentage of males in the population, for the years 1957–1960 combined.

	Month	Mesh size efficiency		Percentage males in catch	Estimated percentage males in population
		Female	Male		
Landbased	May	0.091	0.27	82	60
	June	0.46	0.56	58	52
	July	0.83	0.71	39	43
	August	0.87	0.77	44	47
Mothership	May	0.11	0.37	98	92
	June	0.32	0.46	81	75
	July	0.56	0.59	55	53
	August	0.88	0.80	42	44

* Ratio of catch from a given mesh size to possible catch from optimum mesh size.

region catches. In the landbased region in May, the catch consisted of 82% males and in the estimated population, 60% males. In the mothership fishery in May, there were 98% males in the catch, 92% males in the population. By August, the percentages of males in both fisheries had declined to 42–44% in the catch, 44–47% in the population. About one month elapsed before values in the two regions were reasonably similar. For example, June values in the landbased region were similar to July values in the mothership fishery. The range of values for percentage of males with progression of the season was not as extensive in the estimated sex ratios as in the sex ratios in the catch.

IX. COHO SALMON

A. Catch and Relative Abundance

1. *INPFC Research Vessel Operations*

The distribution and relative abundance of coho salmon, as indicated by research vessel data, are shown in Appendix Figure B-4. The abundance indices are weighted values and were obtained and illustrated in the same manner as abundance indices for the three major species of salmon (Section IV). The data upon which this figure is based are given in Appendix Table C.

Since coho salmon were less abundant and the catches more scattered than those of either sockeye, chum or pink salmon, the distribution of this species has not been considered according to the ten major INPFC regions. Instead, distribution of coho salmon has been examined separately for the North Pacific, Bering Sea and Okhotsk Sea, considering all years collectively.

North Pacific.

During May, coho salmon were caught at widely scattered positions in the North Pacific east of Longitude 170°E south of about Latitude 50°N and eastward into the southeast areas of the Gulf of Alaska. Density levels were low in all areas (CPUE values never exceeded 3), but coho were relatively more numerous in the eastern waters.

In June, when coverage was more extensive than in May, coho salmon appeared to be present slightly further north in the central areas of the North Pacific and throughout the Gulf of Alaska, except in areas adjacent to the Alaska Peninsula. Coho salmon, while still present in low levels of abundance in most areas, were more numerous than in May. Highest abundance levels continued to be recorded in the eastern areas. Fishing in different years in the western Pacific (1957), in the central North Pacific south of about Latitude 43°N (1956) and in the eastern Pacific south of Latitude 46°N (1956) failed to catch coho salmon.

Through July, coho salmon were caught more frequently and their numbers varied regionally more so than in June. However, abundance levels rarely exceeded low levels (Appendix Table C). Off the Kurils, coho salmon were relatively few in number. In the western Pacific, they were more numerous southwest of the Aleutians, where maximal levels occurred (1956, 1957). Further east, south of the Aleutians and eastward into the Gulf of Alaska, their numbers were relatively low. In the latter region, coho were most numerous in the northeastern areas, and were not caught south of about Latitude 50°N.

In August, coho salmon across the North Pacific were caught mainly north of Latitude 48°N, especially

in the eastern Pacific. They were most abundant (moderate levels) southeast of Kamchatka, thus indicating a northwest shift in the area of concentration since July. Further eastward and into the Gulf of Alaska, the abundance levels were lower. In the Gulf of Alaska, coho were most numerous in the coastal areas.

In September, fishing was carried out in some years only, and was confined to the central Aleutians and eastern North Pacific. Only a few coho salmon were caught at widely scattered localities.

Bering Sea.

Even though fishing in different years during late May and June covered virtually all areas south of Latitude 60°N, coho salmon were not caught in these waters until late June. A solitary individual was taken in the central Bering Sea (area E7556) in 1958. Through July, coho salmon were caught generally but by August they occurred largely in coastal areas in the western, mainly, and eastern Bering Sea. Abundance levels were lower than in the North Pacific.

Okhotsk Sea.

Fishing in July of 1959 and 1960, southwest of Kamchatka, indicated that coho salmon were present in very low numbers.

2. *Mothership Operations*

(a) Catch.

The reported annual coho salmon catches by the mothership fleets in the North Pacific, Bering Sea and Okhotsk Sea, by month, for the period 1952–1960 are given in Table 35. The catch in each year, according to statistical areas and cumulative catch by five degrees of longitude for each 10-day period, are shown in Appendix Figure C-4. This figure is based on data contained in Appendix Table D.

North Pacific. The bulk of the coho salmon catch by the mothership fishery was made in the North Pacific. At least 90% of the coho catch was taken in this region in each year from 1952 to 1960, except in 1957, when about 75% was taken there.

Along with the expansion and growth of the fishery, the annual coho catch increased rapidly from 24,000 fish in 1952 to 3.7 million fish in 1956. In 1957, a low catch of 339,000 fish was due to a considerable reduction in the amount of gear fished, a shorter than usual fishing season and (as will be pointed out later) a marked reduction in the relative abundance of coho. In 1958, the catch was again high, 3.3 million fish. Following 1958, the decline in catch was related to reduced fishing effort and shorter fishing seasons.

As already mentioned, the emphasis of the Japanese mothership operation was directed principally towards catching sockeye, chum and pink salmon. This entailed fishing certain waters in some years and not in others. However, because of the large size of the operations and the extensive area covered, the coho catches thus made are considered to provide good information on the distribution of the species and on areas of concentration.

During May, when the fleets operated east of Longitude 165°E, in spite of considerable fishing effort, coho catches during each 10-day period were small, numbering less than 500 fish, and were mainly made in waters to the south. During June, the catches in these waters increased and coho were also caught in waters to the north and west where they had not been taken during May. In July, when operations were mainly centered in waters west of Longitude 165°E, the catches increased rapidly and remained relatively high through the remainder of the season, and exceeded those from waters to the east.

Table 35. Coho salmon catches (in thousands of fish) by Japanese mothership operations, 1952–1960. The " plus " sign represents less than 500 fish.

	North Pacific					Bering Sea					Okhotsk Sea					
Year	May	June	July	Aug.	Total	May	June	July	Aug.	Total	May	June	July	Aug.	Total	Total
1952	—	+	21	3	24	—	—	—	—	—	—	—	—	—	—	24
1953	+	+	212	125	337	—	—	—	—	—	—	—	—	—	—	337
1954	+	+	443	950	1,393	—	—	—	—	—	—	—	—	—	—	1,393
1955	+	4	513	2,190	2,707	—	—	—	—	—	—	1	43	332	376	3,083
1956	—	3	3,051	690	3,744	—	+	1	7	8	—	—	105	13	118	3,870
1957	+	8	331	—	339	—	+	+	—	+	—	+	102	—	102	441
1958	+	4	1,660	1,676	3,340	—	—	—	—	—	—	+	24	27	51	3,391
1959	+	36	1,359	—	1,395	—	+	29	—	29	—	—	—	—	—	1,424
1960	+	1	939	16	956	—	+	+	8	8	—	—	—	—	—	964

The statistical areas yielding the largest catches varied to some extent annually. The important areas were located mainly southeast of Kamchatka and usually included E6050, E5548 and E6048. In later years (1958 and 1959), good catches were also made in areas E7046, E6548 and E6546 during late July and early August.

Bering Sea. Except for 1958, fishing was carried out in this region in each year since 1956. In each year except 1959, when 29,000 coho were caught, the catches amounted to about 8,000 fish, indicating that the species was not abundant in the Bering Sea. Fishing was conducted in many statistical areas from mid-June through July, but coho usually were not caught until during late June. In 1960, they were caught during mid-June, slightly earlier than in other years. The area of greatest production for any 10-day period in any year was E7056 where, during mid-July of 1959, 17,000 coho were caught.

Okhotsk Sea. The total catch in this region declined annually from 376,000 fish in 1955 to 51,000 fish in 1958. Catches were largest during the latter part of the season. The size of the catches was affected both by fluctuations in fishing effort and time of termination of the fishing period. The large catch in August in 1955 was mainly due to a later fishing season than in other years. In that year, 88.3% of the total catch of coho was made in August, almost one-half of this amount being caught during the mid-month period.

(b) Relative Abundance.

Changes in the relative abundance of coho salmon by statistical area and 10-day period for the years 1952–1960, inclusive, are illustrated in Appendix Figure D-4. The relative abundance indices (catch per tan) were computed from catch and effort data given in Appendix Table D.

The relative numbers of coho varied considerably from year to year (Table 36). The distribution pattern of coho salmon for practical purposes, however, can be considered to be somewhat similar during the fishing season in each year.

North Pacific. During the latter half of May and early June, coho were present in relatively very low numbers roughly east of Longitude 165°E and mainly south of Latitude 48°N. Through the latter part of June, their relative numbers increased only slightly. Coho, in fewer numbers, were also present to the north and west, where during May they apparently were absent, indicating some movement in these directions. During early July, a marked increase in relative numbers occurred generally, but the distribution pattern was reasonably similar to that in June. In 1956, when waters east of Longitude 170°E were fished later in the year than in other years, coho were numerous at least as far east as areas E7546 and E7548. In August, when fishing was principally carried out west of Longitude 165°E, peak densities occurred during late July or early August. Thereafter, abundance levels declined. Thus, it would appear that during the early season coho occur mainly in southern areas of the eastern sector fished by motherships (i.e., east of Longitude 165°E). As the season advances, coho migrate northwestward towards Kamchatka increasing in relative numbers until about late July or early August.

Table 36. Annual coho salmon catch per tan values in mothership operations by major fishing region. The "plus" sign represents a value less than 0.05.

Year	North Pacific	Bering Sea	Okhotsk Sea
1952	0.1	—	—
1953	0.3	—	—
1954	0.4	—	—
1955	0.4	—	0.5
1956	0.5	+	0.3
1957	0.1	+	0.2
1958	0.4	—	0.1
1959	0.3	+	—
1960	0.2	+	—

Bering Sea. Catch per tan values indicate that coho were considerably less abundant in the Western and Central Bering Sea regions than in either the North Pacific or the Okhotsk Sea (less than 0.05 fish per tan in each year).

During June and July, the only months fished, coho became available during late June and their numbers increased slightly through the remainder of the fishing season.

Considering indices of relative abundance for 1956–1960, the years when gillnets were reasonably similar, coho were relatively most numerous in 1959.

Okhotsk Sea. Coho salmon have been caught in waters fished by the motherships as early as early June (1955), but were not readily available until towards the end of that month or early July, and then only in relatively small numbers. Their relative numbers increased markedly thereafter during the fishing season, and southward. Maximal concentrations occurred in area E5050. In 1955, peak density

levels formed later in the season in northern waters than in southern waters. This suggests that coho migrate northward in waters off the west coast of Kamchatka.

3. *Landbased Region Operations*

Information on the relative abundance and distribution of coho salmon in this region is based on catch per tan values derived from research and training vessels fishing with 4.5″ mesh gillnets from May into August during the years 1956–1960 (Appendix Table E).

Considering the indices for the same 10-day period in each year collectively, coho salmon would appear to be absent in waters immediately off the Kuril Islands and northern Japan as far south as about Latitude 38°N. They were first caught in very small numbers in mid-May in area E6044 (1959). During June, coho were caught more frequently to the west and north, especially during the latter part of the month. Highest abundance indices were recorded for offshore waters east of the southern Kurils. Through July, their numbers continued to increase generally and the center of abundance was located off the central Kuril Islands (areas E5546, E6046), northwest of the June position. In August, abundance levels offshore declined.

4. *Summary*

Figure 31, based on research and commercial vessel operations, illustrates schematically the occurrence of coho salmon in the North Pacific and the Bering Sea from May through August, mainly. Unlike in similar figures for sockeye, chum and pink salmon, no attempt was made to illustrate monthly changes in abundance levels, since catches by all types of fishing were relatively small thus making regional comparisons difficult.

In May, research and commercial fishing operations indicated that coho salmon were present in the North Pacific south of a line running from northern Honshu (Japan) to about Latitude 48°N, Longitude 165°E. They were also present in the central Pacific as far north as about Latitude 50°N. Research vessel fishing in the Gulf of Alaska indicated presence of the species only in southeastern waters. Abundance levels were very low in all areas but they tended to increase eastward.

During June, coho were slightly more numerous than in May and extended their northern limit in both the western and central Pacific regions. They were present throughout most of the Gulf of Alaska, where they were still most numerous. By the end of the month, they were also present in low numbers in the central areas of the Bering Sea and, according to commercial operations, southwest of Kamchatka in the Okhotsk Sea.

In July, coho were present generally in greater abundance than in June in the North Pacific, Bering Sea and areas fished by motherships in the Okhotsk

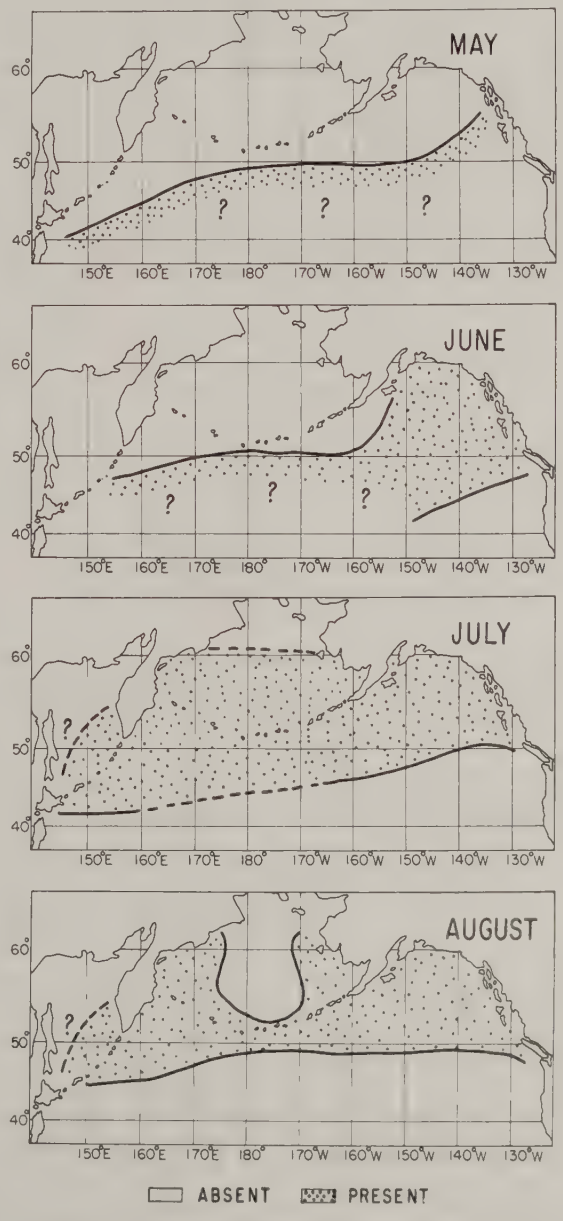

FIGURE 31. Schematic diagram showing occurrence of coho salmon, May through August.

Sea. In the western Pacific, they were most numerous southwest of the Aleutian Islands where they usually occurred as far south as fishing was conducted, suggesting that the main concentration was to the south. In the eastern Pacific, coho salmon would appear to be most abundant in the northeast areas of the Gulf of Alaska. They would appear to be present only north of about Latitude 48°N.

During August, coho were not caught south of about Latitude 44°N in the western Pacific and Latitude 48°N in the eastern Pacific. Also, they appeared to be absent in the Central Bering Sea region. In the areas of the North Pacific and the Bering Sea where coho occurred, their numbers generally were lower than in July. In the western Pacific, the center of abundance had shifted northwestward into waters southeast of Kamchatka. Coho in the Okhotsk Sea areas fished by motherships were more abundant than in July.

In September, in the southern Gulf of Alaska, coho were present at widely scattered locations in low numbers.

B. Age and Maturity of Coho Salmon

1. *INPFC Research Vessel Operations*

Information on the distribution of coho salmon of different ages, caught by research vessels, is available

Table 37. Ages of coho salmon caught in the Gulf of Alaska by Canadian research vessels, 1956 and 1957 combined.

Month	Position °N	Position °W	Age 2_1	3_1	3_2	4_2	4_3	5_3	Total
May—June	55°00′	135°00′	1	1	23	—	—	—	25
	54°53′	134°22′	3	1	18	—	—	—	22
	55°00′	145°00′	1	—	16	—	—	—	17
	52°30′	135°00′	—	—	1	—	—	—	1
	50°00′	155°00′	—	—	13	—	—	—	13
	50°00′	145°00′	—	—	32	—	8	—	40
	50°00′	135°00′	2	1	142	4	7	—	156
	48°00′	135°00′	—	—	1	—	—	—	1
	48°00′	132°30′	—	—	2	—	—	—	2
	46°00′	135°00′	—	—	1	—	—	—	1
	47°39′	126°46′	—	—	1	—	—	—	1
	44°56′	133°38′	—	—	1	—	—	—	1
	Total		7	3	251	4	15	—	280
July	58°00′	137°00′	—	—	7	—	—	—	7
	58°00′	140°00′	—	—	7	—	—	—	7
	58°00′	145°00′	—	—	42	—	1	—	43
	58°00′	150°00′	—	—	1	—	—	—	1
	56°00′	150°00′	—	—	5	—	2	—	7
	56°00′	145°00′	—	—	6	—	2	1	9
	56°00′	140°00′	1	—	3	—	—	—	4
	56°00′	137°00′	1	—	15	2	—	—	18
	55°00′	135°00′	—	—	5	—	—	—	5
	55°00′	145°00′	—	—	1	—	—	—	1
	55°00′	153°17′	—	—	2	—	—	—	2
	54°00′	150°00′	—	—	5	—	—	—	5
	54°00′	145°00′	2	—	3	—	—	—	5
	54°00′	137°00′	—	—	2	—	1	—	3
	52°00′	135°00′	3	—	1	—	—	—	4
	52°00′	145°00′	—	—	3	—	—	—	3
	52°00′	150°00′	—	—	—	—	2	—	2
	Total		7	—	108	2	9	1	127
Aug.—Sept.	54°00′	135°00′	1	—	10	—	1	—	12
	52°00′	135°00′	3	—	1	—	—	—	4
	Total		4	—	11	—	1	—	16

only for the Gulf of Alaska. The data upon which the information is based were obtained from Canadian research vessels operating in 1956 and 1957 during May through August. The data for these two years were combined, and are summarized in Table 37.

Through the season, several age groups were caught but fish of age 3_2 were largely dominant. The next important age group was 4_3.

Regarding the seasonal distribution of these age groups, 3_2 fish were present generally wherever coho salmon were caught. Fish of age 4_3 during May and June were caught only in the southern part of the Gulf of Alaska. After June, they were also present in the northern areas of the Gulf of Alaska.

Since all the coho caught had spent at least one winter in the ocean it is presumed that most were maturing fish.

2. *Mothership Operations*

Information on the ages of coho salmon caught by motherships is available only for 1959 and 1960. The percentage age composition of the samples for these two years is known for large areas and by month and is summarized in Table 38. Judging from the size of the catches in the Bering Sea and in the North Pacific regions east and west of Longitude 170°E, it is presumed that in each of these two years the available information pertains to coho salmon in the North Pacific. Since fishing in the Okhotsk Sea was last carried out in 1958, information on ages of coho caught by motherships in this region is lacking.

In 1959, the samples from each region showed that during May, June and July several age groups were present in the catch. The May samples were extremely small and therefore are not considered further. The June and July samples were reasonably large and probably represented mainly the catches made in areas E7048 and E7046 in the region east of Longitude 170°E, and areas E6048, E6546 and E6548 in the region west of Longitude 170°E, where the bulk of the fishing occurred. In each region, fish of age 4_3 were dominant and were followed in importance by fish of age 3_2. The data also suggest that 3_2's, especially in June, were proportionately more numerous west of Longitude 170°E than east of this meridian. Fish of ages 4_3 and 3_2 formed 60% and 35%, respectively, of the total number sampled. The remaining 5% of the sample largely included fish of age 5_4.

Since the catches in these areas consisted largely of 1-winter-ocean individuals, it is presumed that these fish were mainly maturing.

In 1960, samples were also available from regions east and west of Longitude 170°E, but in contrast to 1959 the samples for waters east of this meridian were divided further according to waters south and north of Latitude 52°N. Samples of reasonable size are available only for July. The important areas of production in this month were E7048, E7046, E6548 and E6048.

TABLE 38. Age composition of coho salmon in samples from mothership operations, 1959 and 1960.

Year	Area	Month	Age composition (percent)								Sample size
			2_2	3_1	3_2	4_2	4_3	5_3	5_4	6_4	6_5	
1959	West of 170°E	May	—	—	8	—	75	—	17	—	—	12
		June	—	—	35	1	60	—	4	—	—	452
		July	—	—	38	1	56	—	5	—	—	482
	East of 170°E	May	—	—	25	—	75	—	—	—	—	4
		June	—	—	21	1	67	2	8	1	—	211
		July	—	—	35	1	58	—	6	—	—	229
1960	East of 170°E, North of 52°N	June	—	—	—	—	50	—	50	—	—	2
		July	—	—	—	—	—	—	—	—	—	
		Aug.	—	—	7	—	72	—	14	—	7	28
	East of 170°E, South of 52°N	June	—	—	14	—	86	—	—	—	—	7
		July	—	1	29	—	65	—	5	—	—	252
		Aug.	—	—	17	—	66	—	17	—	—	6
	West of 170°E	May	—	—	—	—	100	—	—	—	—	2
		June	1	—	25	—	69	—	5	—	—	84
		July	1	—	22	—	69	—	7	—	1	929
		Aug.	—	—	18	—	76	—	6	—	—	17

As in 1959, several age groups were present in the samples and fish of 4_3 and 3_2, probably maturing, were most important. The July samples, the only ones of reasonable size, showed that percentages for each age group were about the same east and west of Longitude 170°E. Fish of age 2_2 in the June and July samples from west of Longitude 170°E were probably immature, and their occurrence indicates that some immatures are present in these waters.

X. CHINOOK SALMON

A. Catch and Relative Abundance

1. *INPFC Research Vessel Operations*

The actual chinook salmon catches by research vessels are listed by set in Appendix Table A. The weighted catch per 3,000 feet of gillnet by set is listed in Appendix Table C.

Appendix Figure B-5 illustrates the weighted data by statistical area. Because chinook salmon catches were fewer and smaller than those of other species of salmon, the weighted values for each year have been grouped by month rather than by 10-day period.

In the North Pacific in May, scattered fishing showed that chinook salmon were present in relatively very low numbers immediately east of Kamchatka (late May 1958) eastward into the southern areas of the Gulf of Alaska (1957). In 1956, they were caught as far south as Latitude 42°N in certain western areas of the North Pacific. In some years (1959, 1960), they were relatively numerous immediately south of the Aleutians. In June, the distribution pattern was very similar to that in May, but in some areas their numbers were slightly higher. During July, abundance levels were relatively much higher than in June, especially in the Aleutian and Western Gulf of Alaska regions, and remained at this higher level into August. In August, the southern limit south of the Aleutians would appear to be about Latitude 48°N. Chinook salmon were virtually absent in the southeast areas of the Gulf of Alaska through May into August.

In the Bering Sea, limited fishing in May in the southwestern areas failed to catch chinook salmon. However, since they were present generally in June in some years as far north as Latitude 60°N, it is presumed that they were also present in May. Relative abundance levels were highest in June and July and dropped rapidly thereafter.

Limited fishing in the southern Okhotsk Sea in July (1959, 1960) indicated that chinook salmon were not particularly abundant. Most operations failed to catch any chinook salmon.

Chinook salmon in the Bering Sea were relatively most abundant in 1956 (eastern Bering Sea), 1958, 1959 and 1960 (generally). Abundance levels in 1957 were lower, especially in the Bering Sea, than in most other years.

2. *Mothership Operations*

(a) Catch.

The reported chinook catches by mothership operations in the North Pacific, Bering Sea and Okhotsk Sea, by month, for the years 1952 through 1960 are given in Table 39. The catch by statistical area and the cumulative catch by intervals of five degrees of longitude for each 10-day period are shown in Appendix Figure C-5. This figure was prepared from data listed in Appendix Table D.

In each year, chinook salmon constituted only a very small fraction of the total mothership salmon catch. The peak year for chinook catches, all major regions combined, was 1960, when the catch amounted to 180,000 fish, or 0.7% of the total salmon catch in that year.

The North Pacific and the Bering Sea were the important chinook salmon regions. In 1956, the catch in the North Pacific was about twice that in the Bering Sea. In 1957 and 1959, the catches in these two regions were about equal. In 1960, the catch in the Bering Sea was about 3.5 times that in the North Pacific. There was no fishing in the Bering Sea in 1958, hence no catch.

In the North Pacific, in almost all years, chinook salmon were caught throughout the season in all areas fished by motherships, indicating that they were widespread. Catches generally were very small in May and June, increased rapidly in July, especially southeast of Kamchatka and remained high or increased further in August, at least in years when fishing was permitted through that month. The largest catch for any statistical area and 10-day period was recorded for area E6048 (13,000 fish) in late July 1956.

In the Bering Sea, the major portion of the catches was made in June, but the important areas of catch were not always the same in each year. In 1956, 1957 and 1960, the bulk of the catch was made in the eastern waters open to commercial gillnetting. In 1959, most of the catch was made in the northwestern areas of the Bering Sea. The largest catch for any statistical area and 10-day period was recorded for area 8058 (49,000 fish) in late June 1960.

TABLE 39. Chinook salmon catches (in thousands of fish) by Japanese mothership operations, 1952–1960. The " plus " sign represents less than 500 fish.

	North Pacific					Bering Sea					Okhotsk Sea					
Year	May	June	July	Aug.	Total	May	June	July	Aug.	Total	May	June	July	Aug.	Total	Total
1952	+	+	1	+	1	–	+	–	–	+	–	–	–	–	–	1
1953	+	+	3	+	3	–	–	–	–	–	–	–	–	–	–	3
1954	+	6	35	33	74	–	+	–	–	+	–	–	–	–	–	74
1955	2	6	12	42	62	–	+	–	–	+	–	1	+	1	2	64
1956	+	7	58	18	83	–	31	12	–	43	–	+	+	–	+	126
1957	1	3	8	–	12	+	15	+	–	15	–	+	+	–	+	27
1958	+	14	18	14	46	–	–	–	–	–	–	+	+	+	+	46
1959	2	12	19	–	33	–	1	29	–	30	–	–	–	–	–	63
1960	1	4	32	1	38	+	123	30	–	142	–	–	–	–	–	180

The catch of chinook salmon in the Okhotsk Sea in any one year never exceeded 2,000 fish, indicating the species to be scarce in the waters fished.

(b) Relative Abundance.

The chinook salmon catch per 10 tans of gillnet is illustrated in Appendix Figure D-5 by statistical area and 10-day period for the years 1952 to 1960. It should be pointed out that, on the average, chinook salmon are larger than the other salmons and that the smaller individuals are more vulnerable to capture by the commercial gillnets. Therefore, the apparent distribution pattern would be more representative of the smaller, younger fish, than of the larger, older individuals.

In the North Pacific in May and June, chinook salmon would appear to be present generally but in very low numbers in all areas fished by motherships. Relative abundance levels increased rapidly in July, particularly during the latter part of the month, and offshore from southeast Kamchatka. The center of abundance in all years in late July and August, periods of peak abundance, was situated between Longitudes 160°E and 165°E. In 1960, the center of abundance was located east of Longitude 170°E.

In the Bering Sea in June, chinook salmon were caught in all areas fished. They were most abundant, however, in the Central Bering Sea region, especially in 1956 and 1960. For corresponding time periods during June they were relatively more numerous than in the North Pacific. In July, relatively good catches were made in 1956, 1959 and 1960.

3. *Landbased Region Operations*

Distribution and relative abundance of chinook salmon in this region, as with the other salmon species, were determined from Japanese research and training vessels using 4.5″ mesh gillnets. The catch per tan values for various areas by 10-day period are given in Appendix Table E. Because of the smaller mesh size used, these catches are even more biased than the mothership catches towards smaller, younger fish.

In May and June, chinook salmon were present in very low numbers throughout the region as far south as waters east of Hokkadio. Their numbers increased through July into August, and northward.

4. *Summary*

The chinook salmon is considerably less numerous than any of the other species of Pacific salmon. Although none was caught in May, chinook salmon would appear to be present in the Bering Sea, since they were relatively abundant there in June, as was pointed out. In the North Pacific, they were present in low numbers off northern Japan northward to southeast Kamchatka (1958) and thence appeared in scattered areas eastward into the southeast waters of the Gulf of Alaska (1957). The southern limit in the central areas of the North Pacific would appear to be about Latitude 42°N. In June, they were present generally in the North Pacific and in the Bering Sea. According to research vessel and commercial operations, they were much more abundant in the Bering Sea. The center of abundance in the Bering Sea in 1956 was located in the Central and Eastern Bering Sea regions. In all other years but 1955 and 1957, when chinook salmon were rather scarce, they appeared to be generally distributed. In July, abundance levels declined in the Bering Sea and increased rapidly in the North Pacific. Mothership operations indicated that in the western Pacific chinook salmon in most years were most numerous south of Latitude 50°N and east of Longitude 165°E. Research vessels indicated that chinook salmon were also numerous in the Aleutian and Western Gulf of Alaska regions.

During August, the increase in numbers south of the Aleutians, immediately off southeast Kamchatka and in the Gulf of Alaska, and the decline in the Bering Sea, noted for July, continued.

According to both commercial and research vessel operations, chinook salmon were relatively scarce in 1957, and rather abundant in 1956, 1959 and 1960. The areas of maximal abundance were not necessarily the same in each year.

B. Age, Length and Sex Ratio of Chinook Salmon

Information on age, fork length and sex ratio of chinook salmon is available for 1960 only for the mothership and the landbased regions.

1. *Age*

The age composition of chinook salmon in samples of catches from the mothership fishery and in the landbased fishery region are given by month in Table 40. The same problems regarding aging of salmon pointed out for other species certainly apply to chinook salmon, but in addition small sample sizes dictate greater reservation in interpreting results, especially as regards research vessel operations.

Chinook salmon of 1-, 2-, 3- and 4-winter-ocean ages were present in the samples from each region. The main age group in 2-winter-ocean fish was 4_2: in 3-winter-ocean fish, 5_2.

Samples of catches from the mothership fishery showed that chinook salmon of 3-winter-ocean age or older were dominant during the early part of the season and were displaced by July by 2-winter-ocean fish. This seasonal change-over was apparent in each region, even though the monthly samples varied considerably in size. The change occurred earlier in the regions east of Longitude 170°E, and was especially pronounced south of 52°N. Comparing July samples from the three regions, the proportion of 3-winter-ocean fish was higher west of Longitude 170°E than east of this meridian.

Possible explanations of this change in age composition are the increased availability of 2-winter-ocean fish through the season as a result of growth or the evacuation of 3-winter-ocean fish, presumably maturing fish, from the high seas areas. The latter explanation is the more likely.

In the landbased region in July, 2-winter-ocean fish (4_2's) were largely dominant.

2. *Length*

The fork length frequency distribution and mean fork lengths of chinook salmon, all ages combined, are

Table 40. Age composition of chinook salmon in samples from mothership operations and from the landbased fishery region, 1960.

Region	Month	Age composition (percent)							Sample size
		3_2	4_2	4_3	5_2	5_3	6_2	6_3	7_3	
East of 170° E, South of 52° N	May	—	15	—	76	—	3	—	6	34
	June	—	35	—	54	—	5	3	3	91
	July	1	85	—	9	5	—	1	—	164
	August	—	90	—	10	—	—	—	—	8
East of 170° E, North of 52° N	June	—	51	—	38	6	1	4	—	465
	July	4	52	—	23	16	—	5	—	56
	August	—	74	—	26	—	—	—	—	19
West of 170° E	May	—	23	—	45	2	13	13	4	71
	June	—	41	—	44	4	6	7	2	317
	July	1	60	1	32	4	—	4	—	675
	August	—	89	—	11	—	—	—	—	9
Landbased, North of 45° N	July	—	84 100 : 81	—	11	1	—	4	—	70
	August	4	59 100 : 78	—	30	4	—	4	—	27
Landbased, South of 45° N	May	—	50 100 : 50	—	50	—	—	—	—	12
	June	—	50 100 : 175	—	—	41	9	—	—	22
	July	—	84	—	12	3	—	1	—	119

ted by region for 1957–1960 in Appendix Table G. able 41 summarizes these data by month and sex, to e nearest centimeter, for the mothership regions, cluding the Okhotsk Sea which was represented by ry small samples. Because of small samples, data r the landbased region are also omitted. The othership data are not corrected for gillnet selec- vity, but nevertheless show some general monthly nd regional differences in lengths of male and female inook salmon.

Annually and regionally, females usually exceeded males in average length. This disparity was quite apparent in May (5–14 cm in different years). By July, males usually were equal in length or only slightly shorter than females. The greatest late-season difference noted in average lengths of the two sexes was 2 cm.

In each region, the average lengths of each sex decreased through each successive month. However,

TABLE 41. Mean fork length (cm) of male and female chinook salmon in samples of mothership catches, by region, 1957–1960.

Region	Month	1957		1958		1959		1960**	
		Male	Female	Male	Female	Male	Female	Male	Female
East of 170° E	May	78	71	75	65	83*	60*	73*	72*
	June	62	59	67	63	67	62	72	64
	July	55	54	62	62*	60	59	60	61
East of 170° E, North of 52°N	June	—	—	—	—	—	—	62	60
	July	—	—	—	—	—	—	60	59
	August	—	—	—	—	—	—	66*	63*
West of 170° E	May	—	—	72	67	78	64	77	69
	June	65*	63*	69	63	66	61	70	65
	July	62	62	62	61	63	61	64	62
	August	—	—	61	61	—	—	64*	64*

* Mean length based on less than 50 fish.

** In 1960 only, the region east of Longitude 170° E was divided into north and south regions by Latitude 52°N.

TABLE 42. Percentage* of 4_2 and 5_2 male chinook salmon in samples from mothership and landbased regions, by month, in 1960.

Region	Month	4_2		5_2	
		No. of fish	Percent males	No. of fish	Percent males
East of 170° E, North of 52°N	June	236	53	177	33
	July	29	55	13	31
	August	14	57	5	40
East of 170° E, South of 52°N	May	5	80	26	27
	June	32	72	49	49
	July	140	53	14	43
	August	7	57	—	—
West of 170° E	May	16	81	33	49
	June	129	81	139	41
	July	403	59	214	36
	August	8	38	—	—
Landbased, North of 45°N	July	58	45	—	—
	August	16	44	—	—
Landbased, South of 45°N	May	6	33	—	—
	June	11	64	—	—
	July	100	55	—	—

* Rounded values.

in 1959 and in 1960, years in which chinook salmon were relatively abundant, the average length in June was greater in offshore regions. In July, this situation was reversed, suggesting that the larger fish had departed from the high seas towards coastal areas. This observation supports the assumption regarding movement of chinook salmon made earlier when considering age data.

3. *Sex Ratio*

The sex ratio in chinook salmon, expressed as percentage of males, for the two most important age groups, 4_2 and 5_2, is summarized by region and month for 1960 in Table 42. This table was prepared from data given in Appendix Table G. The data are not corrected for the effects of gillnet selectivity.

In the mothership regions throughout the season, male chinook salmon were consistently more numerous in the 4_2 than in the 5_2 age group.

Some regional variation in sex ratio is indicated in each age group at least in June, the only month for which reasonably large samples are available. Male chinook salmon were proportionately more numerous west of Longitude 170°E than east of Longitude 170°E. The samples for the latter region probably were from the central Bering Sea, since in June the fishery was mainly centered there.

In the landbased region in July, in the 4_2 age group, males were more numerous in the southern areas.

XI. SALMON DISTRIBUTION IN RELATION TO SEA-SURFACE TEMPERATURES

In the foregoing sections, changes in the distribution of each species of salmon during May through August, mainly, have been described. These changes were due to maturing fish leaving the high seas areas for their spawning grounds and to immature individuals responding to environmental factors influencing their growth and survival. As could be expected where closely related species are concerned, some overlap in distribution existed, the overlap being greater between some species than between others.

It is generally recognized that several environmental factors such as temperature, food, currents, duration of ocean residence, etc., influence salmon distribution. During some parts of a species' marine existence, one factor can be more important than another, or may be limiting. In the following paragraphs, the relation of water temperature to distribution is considered. Consideration is confined to temperature conditions in surface waters, that stratum where salmon catches were made. Attempts along this line have been made by several authors (Kaganovsky, 1949; Taguchi, 1957; Kasahara, 1961; and others) in a general way, but in almost all instances their observations have dealt with particular species only, usually sockeye, chum or pink salmon; with only a relatively small part of the overall oceanic range of the species; with frequently only a short period of time; and without regard to possible differences in environmental requirements for immature and maturing individuals.

In attempting to evaluate the extent to which any given environmental factor influences the distribution and abundance of any organism, ideally some measure of density of the population should be examined in relation to the factor in question. With salmon, possibly more so than with other marine species of fish, this approach is less than satisfactory for several reasons. For example, the total oceanic population of each species in any one year consists of many stocks of various sizes and origins. Also, as shown by tagging (Hartt, 1962; INPFC, 1958–1961) and racial studies (INPFC, 1957–1961), these stocks occur over extensive high seas areas and frequently overlap in time and space with other stocks during part of their ocean residence. Further, with the exception of pink salmon and possibly coho salmon, the duration of ocean residence of members of some stocks belonging to a particular yearclass can vary depending upon the age at which they mature. This variation in the onset of maturity conceivably could provide fish which mature at an older age with greater opportunity for wider dispersion on the high seas than those fish which mature at a younger age. These factors, therefore, independently or in combination influence or mask the extent to which any correlation between salmon distribution, as shown by relative numbers, and environmental factors can be found to exist.

In the present study, the relationship between the various salmon species and sea-surface temperatures has been determined by examining the frequency with which each species was caught in waters of different temperatures. The findings are based on fishing operations and associated temperatures observed by research gillnet vessels in each year from 1955 to 1960 while operating over vast regions of the North Pacific and the Bering Sea from May into September. The data by set are given in Appendix Table A.

The observed sea-surface temperatures ranged from 1.2° to 19.1°C. The number of fishing operations made at each temperature and the number of these

TABLE 43. Number of fishing operations yielding catches of salmon, by sea-surface temperature and species. The table combines data for 1955–1960.

Temp. (°C)	May						June						July						August						September					
	No. of sets	No. of sets with salmon					No. of sets	No. of sets with salmon					No. of sets	No. of sets with salmon					No. of sets	No. of sets with salmon					No. of sets	No. of sets with salmon				
		Sock.	Chum	Pink	Coho	Chin.		Sock.	Chum	Pink	Coho	Chin.		Sock.	Chum	Pink	Coho	Chin.		Sock.	Chum	Pink	Coho	Chin.		Sock.	Chum	Pink	Coho	Chin.
1— 1.9	2	2	2	0	0	0	3	0	3	2	0	0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2— 2.9	4	3	3	3	0	1	6	2	6	3	0	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3— 3.9	9	9	8	8	0	0	14	12	14	13	0	6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
4— 4.9	30	27	29	15	0	4	49	49	49	44	0	12	1	0	1	0	0	0	—	—	—	—	—	—	1	0	0	—	0	0
5— 5.9	34	34	33	29	1	7	124	123	23	111	6	44	4	4	4	4	0	1	—	—	—	—	—	—	—	—	—	—	—	—
6— 6.9	12	12	12	7	2	2	60	60	58	51	18	28	29	21	29	23	8	9	5	1	4	1	1	0	3	1	0	—	0	0
7— 7.9	10	9	9	6	3	1	19	18	19	16	2	5	48	35	45	25	19	14	7	7	6	3	7	5	2	0	0	—	0	1
8— 8.9	6	6	4	2	3	1	16	16	14	11	2	1	71	55	69	52	51	20	11	9	10	3	5	4	1	1	1	—	0	0
9— 9.9	7	4	4	5	4	0	13	13	10	11	5	1	60	51	60	45	45	21	54	51	53	25	31	16	5	4	4	—	1	1
10—10.9	6	1	3	2	1	1	9	8	8	8	7	1	52	44	48	36	40	17	80	76	79	36	49	26	16	11	15	—	2	2
11—11.9	10	1	8	4	4	1	6	3	2	3	4	0	50	47	47	36	27	7	45	36	39	14	21	17	13	6	9	—	0	0
12—12.9	2	1	0	1	0	0	3	1	1	1	1	0	20	14	12	11	8	2	32	22	23	9	10	6	6	2	4	—	0	0
13—13.9	1	0	0	0	0	0	3	1	1	1	1	0	16	12	5	7	5	0	25	15	20	9	10	2	8	0	1	—	0	0
14—14.9	—	—	—	—	—	—	3	0	0	0	0	0	2	1	1	1	1	0	17	5	8	7	5	0	8	0	0	—	0	0
15—15.9	1	0	0	0	0	0	—	—	—	—	—	—	1	1	1	1	1	0	18	4	5	8	9	0	3	0	0	—	0	0
16—16.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	8	0	0	0	0	0	—	—	—	—	—	—
17—17.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3	0	0	0	0	0	—	—	—	—	—	—
18—18.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	0	0	0	0	0	—	—	—	—	—	—
19—19.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	0	0	0	0	0	—	—	—	—	—	—

operations in which the different species were caught are shown by month in Table 43.

Two general features are apparent from Table 43. First, the temperature range for each species was not exactly the same. Second, the temperature spectrum for each species changed similarly through the study period. From May through July and August, catches became associated with a slightly higher temperature regime with each successive month. During September, with surface temperatures still relatively high, catches were once again made in waters of lower temperature.

Changes in the catch-temperature association can be explained by seasonal warming of the surface waters and by differences in general distribution patterns between immature and maturing individuals. The latter phenomenon, pointed out for both sockeye and chum salmon in previous sections dealing with general distribution, is apparent in Table 44, which was prepared from catches for which the maturity status of individual salmon could be assessed and shows the number of operations in which immature or maturing individuals formed more than 50% of the catch. In general, the temperature ranges within which each group dominated overlapped. However, during the early months, maturing individuals were associated with slightly colder temperatures than were immature individuals. By August and September, with both categories having similar maximal limits, maturing fish, in contrast to earlier months, tended to be taken in waters of higher temperature.

Considering Tables 43 and 44, probable tolerable and " preferred " temperature ranges for each species

TABLE 44. Number of fishing operations in waters of different sea-surface temperatures in which maturing (M) and immature (I) sockeye and chum salmon dominated, by month.

Temp. (°C)	May			June			July			August			September		
	No. of operations	Dominant		No. of operations	Dominant		No. of operations	Dominant		No. of operations	Dominant		No. of operations	Dominant	
		M	I		M	I		M	I		M	I		M	I
SOCKEYE															
3— 3.9	5	5	0	2	2	0	—	—	—	—	—	—	—	—	—
4— 4.9	11	11	0	14	13	1	—	—	—	—	—	—	—	—	—
5— 5.9	3	3	0	23	21	2	—	—	—	—	—	—	—	—	—
6— 6.9	8	6	2	11	9	2	1	1	0	—	—	—	1	0	1
7— 7.9	9	6	3	10	6	4	1	0	1	—	—	—	—	—	—
8— 8.9	6	5	1	17	11	6	7	2	5	—	—	—	1	0	1
9— 9.9	4	3	1	10	4	6	16	5	11	1	0	1	5	0	5
10—10.9	1	0	1	8	7	1	17	8	9	15	0	15	16	0	16
11—11.9	1	1	0	3	2	1	34	16	18	10	4	6	13	0	13
12—12.9	1	0	1	1	1	0	11	9	2	4	0	4	6	0	6
13—13.9	—	—	—	2	2	0	10	9	1	9	1	8	—	—	—
14—14.9	—	—	—	—	—	—	—	—	—	7	2	5	—	—	—
15—15.9	—	—	—	—	—	—	1	1	0	4	1	3	—	—	—
CHUM															
1— 1.9	—	—	—	3	3	0	—	—	—	—	—	—	—	—	—
2— 2.9	1	1	0	4	4	0	—	—	—	—	—	—	—	—	—
3— 3.9	7	7	0	6	6	0	—	—	—	—	—	—	—	—	—
4— 4.9	19	18	1	19	16	3	—	—	—	—	—	—	—	—	—
5— 5.9	15	13	2	58	35	23	1	0	1	—	—	—	—	—	—
6— 6.9	8	7	1	26	16	10	13	3	10	1	0	1	—	—	—
7— 7.9	8	7	1	19	12	7	31	8	23	1	0	1	—	—	—
8— 8.9	5	4	1	15	11	4	37	7	30	4	0	4	—	—	—
9— 9.9	6	2	4	9	5	4	39	3	36	19	1	18	2	0	2
10—10.9	2	0	2	8	5	3	41	3	38	42	2	40	5	1	4
11—11.9	2	0	1	2	1	1	42	5	37	30	2	28	7	0	7
12—12.9	—	—	—	1	0	1	11	2	9	20	1	19	3	1	2
13—13.9	—	—	—	2	0	2	6	3	3	17	3	14	2	1	1
14—14.9	—	—	—	—	—	—	1	0	1	8	3	5	—	—	—
15—15.9	—	—	—	—	—	—	1	1	0	5	1	4	—	—	—

TABLE 45. Probable tolerable and preferred sea-surface temperatures for Pacific salmon.

Species	Tolerable range(°C)	Preferred range(°C)	Reference months for preferred range
Sockeye	<1—15	2,3 —9	May, September
Chum	<1—15	2,3—11	May, September
Pink	3—15	4—11	May, June
Coho	5—15	7—12	May, June, July
Chinook	2—13	7—10	July, August, September

of salmon are indicated. For each species, the tolerable range was regarded to lie between the highest and lowest sea-surface temperatures within which it was caught. The preferred range of a given species was determined from only those months during the period of study when its distribution is considered to be least affected by changes resulting from the spawning migration, and from those temperatures at which a certain minimum percentage of fishing operations produced fish. Because of great differences in the availability between species, largely the result of differences in total population size, the percentage level chosen to indicate temperature preference was not the same for each species. The percentage level, arbitrarily chosen, was set at 60% for sockeye, chum and pink salmon and 30% for coho and chinook salmon.

The probable tolerable and preferred temperature limits for each species and the periods on which these limits were based are summarized in Table 45. Differences in the thermal environments are indicated for the various species.

The highest water temperature in which each species except chinook salmon was caught was 15°–15.9°C. Chinook salmon were caught in waters as high as 13°–13.9°C. Greater variability occurred in the lowest temperatures at which each species was caught. Sockeye and chum salmon were caught in water temperatures as low as 1°–1.9°C. The minimal tolerable temperature was highest for coho, about 5°–5.9°C.

Some differences in preferred temperature limits for each species were also apparent. The minimum preferred temperature for sockeye and chum could not be clearly established, but could be as low as 2° or 3°C, since a very high proportion of the sets at these temperatures, although relatively few, indicated individuals of these species to be present in large numbers (Appendix Table C). The minimum preferred temperature for coho and chinook was highest of the five species, 7°C, while that for pink salmon was slightly higher than that for sockeye and chum salmon and appeared to be about 4°C. The salmon species in order of colder to warmer preferred water temperatures are as follows: sockeye, chum, pink, chinook and coho salmon.

The seasonal distribution of each species, except the chinook salmon because of paucity of catches, in surface waters can be inferred from Figure 32 which shows the configuration of surface isotherms for February,

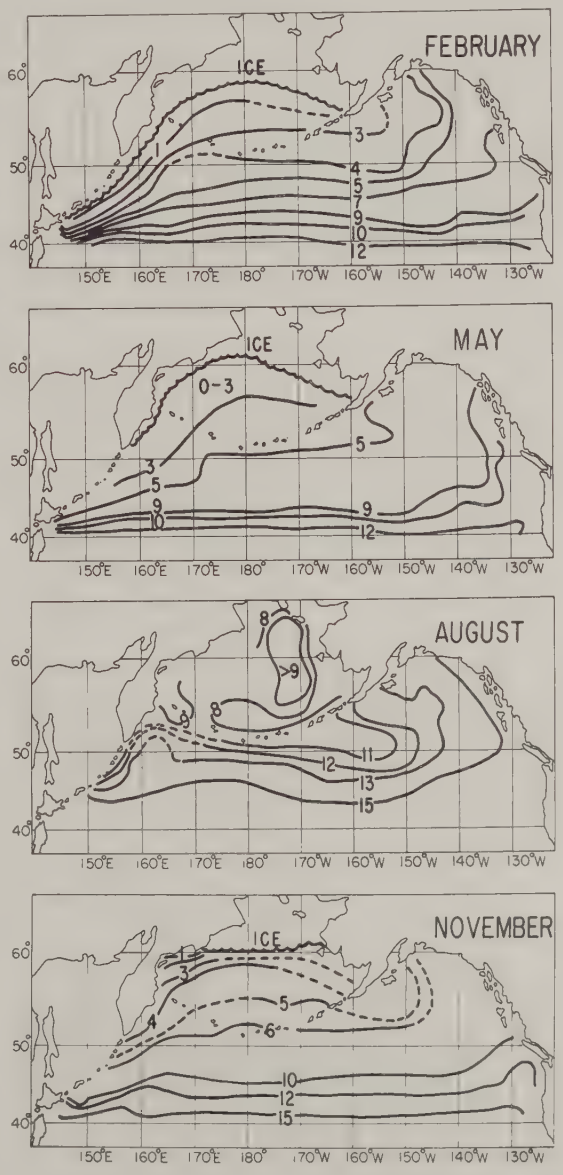

FIGURE 32. Distribution of sea-surface isotherms in the North Pacific and Bering Sea during February, May, August and November. Prepared from Dodimead *et al.* (1963) and *Atlas of the Seas* (U.S.S.R. Ministry of the Navy).

May, August and November. Information on sea-surface temperatures for the North Pacific was obtained from Dodimead *et al.* (1963) who presented mean sea-surface temperatures for each calendar month in 1956, based on information provided by Saur and Eber (1962). Temperature conditions for the Bering Sea were obtained from *Atlas of the Seas* published by the U.S.S.R. Ministry of the Navy (1952). Since February and August are periods when the cooling and heating processes, respectively, at least in the northeast Pacific (Tabata, 1961), are becoming minimal, it is assumed for any species that the greatest seasonal difference in distribution would be represented by the distribution pattern of its limiting temperatures in these two months.

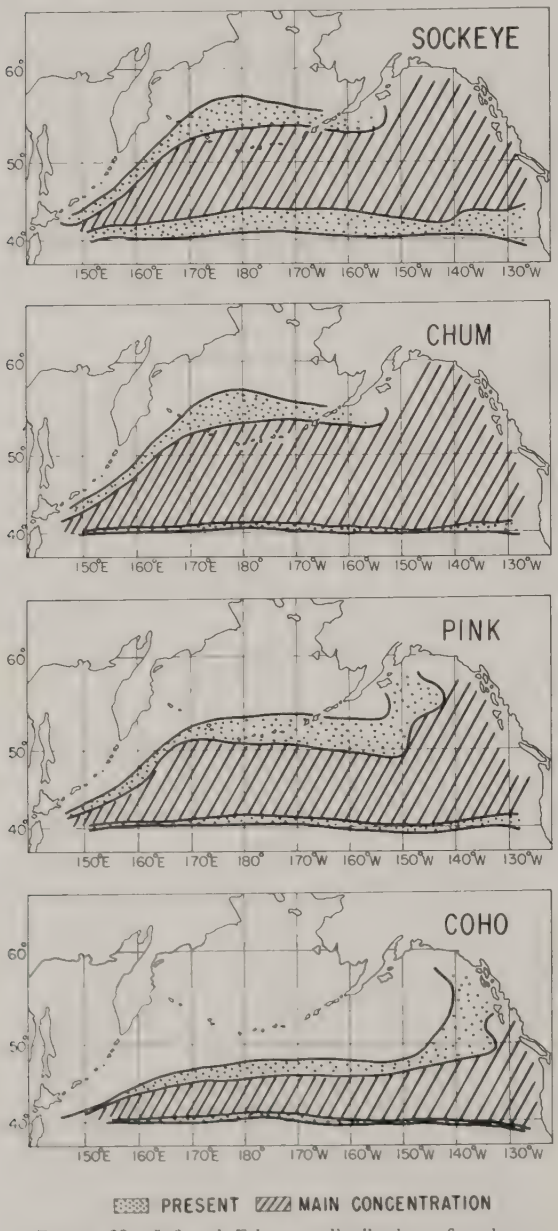

FIGURE 33. Inferred February distribution of sockeye, chum, pink and coho salmon in the North Pacific and Bering Sea.

According to Figure 32, the distribution of sockeye salmon can be expected to change through the year. In February, in some years, preferred sea-surface temperatures occur in the Bering Sea, especially in the southern areas adjacent to the Aleutian Islands, and extend southward into the North Pacific to approximately Latitude 45°N. The presumed distribution of sockeye salmon in February is illustrated in Figure 33. Through the spring and summer months, as seen from the distribution of surface isotherms for May and August, sea-surface temperatures increase and the region of favourable temperatures contracts from the south and east. Reference to Figure 12, which depicts the monthly distribution of sockeye, shows a northward shift in the southern limit through these months. This phenomenon is more clearly shown in Figure 34, which is based on research vessel catches made in 1956, a year when research vessels fished over a wide area of the North Pacific through much of the season. This figure also shows that in the central Pacific where the distribution of sockeye, especially during the latter

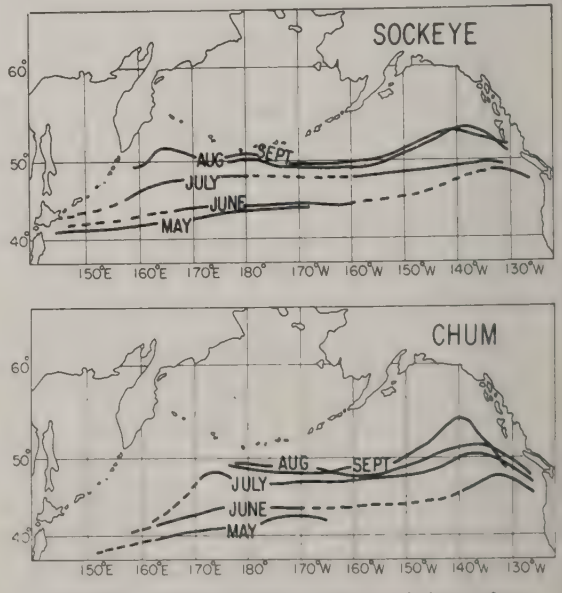

FIGURE 34. Southern limit of sockeye and chum salmon in the North Pacific, May into September.

months, is least affected by migrating maturing individuals, the southern limit of sockeye in most cases roughly coincided with the 10° and 11°C isotherms (Figure 32), temperatures not too different from the presumed upper limit of the preferred temperature range for the species. By November, as a result of cooling, the territory with preferred temperatures available to sockeye expands southward and eastward. As a result, sockeye can be expected to move to areas where only a few months previous they were absent.

Chum salmon, judging from their temperature limits, can be expected to occur in surface waters having temperatures at least as low as those in which sockeye are caught. Since the chum salmon prefers slightly warmer temperatures than the sockeye salmon, the former species can be expected to occur further south and east than the sockeye salmon. This conjecture is consistent with fishing results for the central Pacific Ocean in 1956 from May through September (Figure 34) and is strongly suggested for the northeast Pacific for most years although fishing was rather sparse in this region (Appendix Figure B). The northward shift in the southern limit from May into September as surface waters warm up, noted for sockeye salmon, is also apparent for chum salmon. If a temperature relationship as described persists into the winter months, chum salmon during February may be present as far south as about Latitude 42°N or 43°N (Figure 33).

Pink salmon, before actively undertaking their spawning migration—that is, prior to June—can be expected to occur as far south and east as chum salmon. Indeed, four pink salmon, ranging in length from 36 to 40 cm, were caught in late April at approximately 41°30′N, 165°W in 10°C water (personal communication, G. Murphy, 1958). Since the lower tolerable and preferred temperatures for pink salmon are slightly higher than those for chum salmon, the northern limit of pink salmon is probably south of the northern limit of chum salmon. Thus, it is conjectured that some pink salmon are present in waters immediately south of the central Aleutian Islands in February but the main concentration is further south and east (Figure 33).

Research vessel catches certainly indicated this to be the case in late May, as some pink salmon were taken in the southern Bering Sea, but larger and more consistent catches were made in the North Pacific (Appendix Figure B).

In some years, pink salmon were not caught in waters having preferred temperatures. This phenomenon is best shown by fishing results for May 1956 (Appendix Table C). In that year, pink salmon were caught in the central Pacific area, where temperatures ranged from 4.3°C to 10.4°C, and relatively good catches were made in waters having temperatures above 5°C. In contrast, in the western Gulf of Alaska, limited fishing in waters ranging from 4.2° to 6.8°C failed to catch any pink salmon. This difference in the apparent temperature relationship is presumably associated with the oceanic distribution pattern of major stocks originating from widely separated regions, but also raises the possibility that different stocks may have slightly different temperature preferences.

Regarding the coho and chinook salmons, it is obvious that these species prefer water of warmer temperatures than the other three species. Accordingly, coho and chinook salmon concentrations by comparison are probably most southerly in their occurrence. The presumed distribution of coho in February is shown in Figure 33.

The hypothesis that salmon evacuate the Bering Sea and northwestern Pacific in the winter as surface water temperatures decrease and move southward and eastward into areas where favourable water temperatures still prevail is not new. This hypothesis was first advanced by Kaganovsky (1949) when dealing mainly with pink salmon and was subsequently extended to certain other species by other investigators. The findings of the present study corroborate these views and, in addition, as a result of a somewhat clearer description of thermal requirements of the individual species, have made it possible to deduce from sea-surface temperature data for the different seasons the areas of favourable temperature and likely areas of concentration of the individual species. This deduction would indicate also that some sockeye and chum salmon are present in the Bering Sea and to the southward in the western North Pacific as well as in the central and eastern North Pacific in February as well as in May, a possibility not considered by earlier investigators.[1] Indeed, in years when water temperatures are relatively high, these two species may be present in the southern Bering Sea throughout the winter months. Pink salmon, because of their preference for slightly warmer water temperatures, are probably absent in the Bering Sea and western North Pacific during the winter, but may be present immediately south of the central Aleutian Islands.

[1] Since this study of the relationship between sea-surface temperatures and salmon distribution was made, sockeye salmon were caught during January in the Bering Sea along Longitudes 180° and 175°E (Hunter and Larkins, 1963).

XII. RELATIVE IMPORTANCE OF THE PACIFIC SALMON SPECIES

The preceding sections have dealt with catch, distribution and relative abundance of salmon on an individual species basis. The purpose of this section is to consider temporal changes in the catch and species composition of salmon in the different regions of the North Pacific and the Bering Sea. Since the Protocol to the International Convention for the High Seas Fisheries of the North Pacific Ocean requires the study of the high seas distribution of salmon without reference to individual species, such a consideration appears essential.

In this regard, two sources of data are examined, namely, *mothership catches* from 1955 to 1960, the period of full development of the fishery, and *relative abundance indices of salmon as indicated by INPFC gillnet operations.* Because of the magnitude and intensity of the fishery, mothership catches obviously are better suited to reveal the importance of the various regions as "salmon waters" and also to indicate the species composition in the catches in each region, but only in waters west of Longitude 175°W. Research vessels, in contrast to mothership operations, operated at low intensity but throughout the North Pacific and the Bering Sea. Although thorough coverage in any one year was not possible with the comparatively small numbers of research vessels involved, and with the various objectives for which cruise patterns were designed, the data nevertheless are useful for providing supplementary information on the relative importance of the different regions as salmon waters, especially those regions east of Longitude 175°W. The fact that similarities in monthly trends for particular years have been noted in eight of 12 cases when catch per unit of effort data for research vessels and mothership operations in regions west of Longitude 175°W were compared, even though the regions for the two kinds of operations did not have exactly the same boundaries, supports this view (Table 46).

When considering the data from these two sources, it should be kept in mind that several factors affect their usefulness. First, the fishing periods and locations in each region were not necessarily the same each year. This factor, in conjunction with varying regional distribution and availability (as a result of different yearclass strengths) of the individual species, would influence the extent to which each species was represented in the catches. Also, with commercial operations, economic conditions and regulatory measures influence the presence of one species more than another in the catches, even though the species occur together. Further, fishing effort could be

TABLE 46. Comparison of catch per unit of effort data for research vessel (RV) and mothership (MS) operations east and west of Longitude 170°E, by region and by year.

Date		North Pacific W of 170°E		North Pacific E of 170°E		Bering Sea W of 170°E		Bering Sea E of 170°E	
		RV	MS	RV	MS	RV	MS	RV	MS
1956	May	—	—	9	4	—	—	—	—
	June	36	3	31	9	—	—	19	3.8
	July	54	11	—	—	—	—	37	4.2
	Aug.	38	5	—	—	—	—	—	—
1957	May	35	5	—	—	—	—	—	—
	June	90	8	—	—	—	—	65	9
	July	56	10	—	—	—	—	48	3
1958	May	9	4	9	3	—	—	—	—
	June	10	5	68	3.1	—	—	—	—
	July	—	—	—	—	—	—	—	—
	Aug.	35	6	52	5.5	—	—	—	—
1959	May	—	—	38	4.2	—	—	—	—
	June	—	—	39	4.8	—	—	40	6.0
	July	—	—	112	8.9	—	—	45	8.5
1960	May	—	—	23	3.6	—	—	—	—
	June	21	4.0	51	3.2	27	4.2	—	—
	July	—	—	72	2.9	114	5.0	—	—
	Aug.	31	3.5	62	3.9	38	4.0	—	—

deployed in such a manner as to maintain contact with the more desirable species. These and other factors operated, each at different times, and can be expected to affect the results of any study regarding interrelationship between species. Regardless, at least for the regions consistently exploited or sampled, the more obvious features regarding changes in the annual and seasonal status of the individual species in relation to the total salmon population in each region can be deduced.

A. According to Mothership Operations

During the period 1955–1960, mothership operations caught 284 million salmon (Table 47). Pink salmon formed the highest fraction of this total (36.5%) and were followed by chum (32.3%), sockeye (26.4%), coho (4.6%) and chinook salmon (0.2%). In individual years, the pink salmon was the dominant species in the odd-numbered years (1955, 50.8%; 1957, 46.2%; 1959, 44.7%), the chum salmon in 1956 (38.2%) and 1958 (37.8%) and the sockeye salmon in 1960 (49.0%).

The North Pacific west of Longitude 170°E produced the largest total salmon catch, by virtue of the large fishing effort; as a general rule, regionally, catch was proportional to fishing effort (Table 47).

Table 47. Salmon catches and number of tans of gillnet fished by motherships, by region and by year, 1955–1960. The " plus " sign represents less than 500 fish.

Region	Year	1,000's of tans	Catch (in 1,000's of fish)					
			Sockeye	Chum	Pink	Coho	Chinook	Total
North Pacific								
West of 170° E	1955	5,905	8,151	12,018	13,688	2,695	60	36,612
East of 170° E	1955	1,085	2,252	3,531	553	+	2	6,338
West of 170° E	1956	2,864	3,147	3,731	11,403	2,274	54	20,609
East of 170° E	1956	4,345	3,842	7,184	10,371	1,470	25	12,892
West of 170° E	1957	4,259	11,015	6,110	15,546	339	10	33,020
East of 170° E	1957	946	2,801	1,592	1,480	+	2	5,875
West of 170° E	1958	7,428	10,497	14,807	12,979	3,251	43	41,577
East of 170° E	1958	1,166	1,472	2,361	222	89	3	4,147
West of 170° E	1959	3,929	5,774	7,981	7,219	831	26	21,831
East of 170° E	1959	1,610	1,792	2,946	2,155	559	6	7,458
West of 170° E	1960	3,549	7,703	5,562	791	447	24	14,527
East of 170° E	1960	1,084	1,824	939	68	507	16	3,354
West of 170° E	Sub-total	27,934	46,287	50,209	61,626	9,837	217	168,176
East of 170° E	Sub-total	10,236	13,983	18,553	4,849	2,625	54	40,064
	Total	38,170	60,270	68,762	66,475	12,462	271	208,240
Bering Sea								
West of 170° E	1956	74	271	620	1	+	+	892
East of 170° E	1956	2,028	1,964	4,542	97	8	47	6,658
West of 170° E	1957	40	72	23	357	+	+	452
East of 170° E	1957	1,367	5,939	1,533	3,664	+	15	11,151
West of 170° E	1959	162	179	346	1,275	4	1	1,805
East of 170° E	1959	1,395	1,380	1,583	8,209	30	30	11,232
West of 170° E	1960	140	95	278	521	—	9	903
East of 170° E	1960	1,745	3,257	3,708	695	8	133	7,801
West of 170° E	Sub-total	416	617	1,267	2,154	4	10	4,052
East of 170° E	Sub-total	6,535	12,540	11,366	12,665	46	225	36,842
	Total	6,951	13,157	12,633	14,819	50	235	40,894
Okhotsk Sea	1955	696	300	2,961	8,614	357	2	12,234
" "	1956	470	657	3,225	5,367	118	+	9,367
" "	1957	539	275	2,661	6,834	102	+	9,872
" "	1958	393	54	1,622	2,348	51	+	4,075
" "	Total	2,098	1,286	10,469	23,163	628	2	35,548
	Grand total		74,713	91,864	104,457	13,140	508	284,682

A total of 168 million salmon was caught in this region as compared to 40 million in the region east of Longitude 170°E, 37 million in the Bering Sea east of Longitude 170°E, four million in the Bering Sea west of Longitude 170°E and 36 million in the Okhotsk Sea.

Considerable variation occurred in the relative importance of the individual species in each region. In the North Pacific west of Longitude 170°E over the six-year period, pink salmon dominated (36.6% of the combined annual catches) and were followed by chum (29.9%), sockeye (27.5%), coho (5.8%) and chinook salmon (0.2%). In 1955, 1956 and 1957, the pink salmon was the dominant species followed by the chum salmon in 1955 and 1956, and by the sockeye salmon in 1957. In 1958 and 1959, chum salmon formed the highest fraction of the regional catch, followed by pink salmon. Sockeye were of primary importance in 1960 only, and were succeeded by chum salmon. Also in 1960, in contrast to other years, pink salmon formed a very small portion of the catch and were almost equalled in numbers by coho salmon. Coho and chinook salmon annually were relatively unimportant, ranking fourth and fifth, respectively. In 1956, however, when fishing west of Longitude 170°E was prohibited until mid-July, roughly the period when coho salmon in the region start increasing in numbers, this species formed a higher fraction of the catch than usual (11% as compared with 6% for the six-year period).

In the North Pacific east of Longitude 170°E over the six-year period, chum salmon dominated (46.4%) and were followed by sockeye salmon (35.0%) and pink salmon (12.1%). Coho and chinook salmon were relatively unimportant and formed about the same small fractions of the total catch that they did in the North Pacific west of Longitude 170°E. Considering individual years, chum salmon ranked first in importance in 1955, 1956, 1958 and 1959. In 1957 and 1960, sockeye salmon superseded chum salmon in importance. Pink salmon in each year but 1959, when their numbers were second highest in the catch, ranked either third or fourth in importance.

In the Bering Sea, during the four years of fishing (1956, 1957, 1959, 1960), the total salmon catch east of Longitude 170°E greatly exceeded that from the region west of Longitude 170°E. In 1956, in each region, of the three major species, the chum salmon was the most important in the catch, followed by the sockeye. Pink salmon catches were very small. In 1957, when the total Bering Sea catch amounted to 11.6 million salmon, the sockeye salmon ranked first in importance, forming about half the catch, and was the dominant species east of Longitude 170°E, followed in rank by the pink and chum salmons. West of Longitude 170°E, however, where catches were considerably smaller, pink salmon were most important. In 1959, in each region, pink salmon largely dominated the catch (9.5 of a total of 13 million) and were followed by much smaller numbers of chum and sockeye salmon, respectively. In 1960, the relative importance of the salmon species east and west of Longitude 170°E differed. East of Longitude 170°E, where most of the catch was made, chum salmon dominated but were closely followed in importance by sockeye salmon. Pink salmon, for an even-numbered year, were relatively numerous and ranked third. Unusual for an even-numbered year, the pink salmon was the dominant species west of Longitude 170°E. Coho salmon catches were very low in all years and were outranked by those of chinook salmon, especially in 1960 and 1956.

In the areas fished commercially in the Okhotsk Sea, the significant feature was the great importance of pink salmon in the catches, particularly in the odd-numbered years. Although all five salmon species were caught, the pink salmon was the dominant species annually during the four years fished (1955–1958), forming between 70% (1955 and 1957) and 57% (1956 and 1958) of the total annual salmon catch. Chum salmon in each year ranked second in numbers, ranging from 24% (1955) to 40% (1958) of the annual catch. Sockeye and coho salmon were of minor importance and chinook salmon were virtually absent in the catches. In 1955, because of the late fishery, the catch of coho salmon exceeded that of sockeye salmon.

In addition to annual regional variations in the relative importance of the individual species, the importance of each species varied monthly (Table 48). This monthly variation in species composition was mainly due to the different migratory patterns of maturing and immature individuals within as well as between species.

In May, except for area E7052 (vicinity of Attu Island) in the Bering Sea, catches were only made in the two North Pacific regions. In each of the six years from 1955 to 1960, maturing sockeye and chum salmon were virtually the only salmon caught, chum salmon predominating in each year but 1957 and 1960. Pink salmon ranked third in importance annually and amounted to only a very small fraction of the catch. Coho and chinook salmon catches were negligible.

TABLE 48. Salmon catches (in thousands of fish) by motherships, by region and by month for individual years, 1955–1960. The " plus " sign represents less than 500 fish.

		West of 170° E					East of 170° E				
		Sockeye	Chum	Pink	Coho	Chinook	Sockeye	Chum	Pink	Coho	Chinook
North Pacific											
May	1955	775	1,210	43	–	1	1,641	2,275	31	+	1
	1956	444	823	26	–	+	1,381	3,661	24	–	+
	1957	3,837	2,622	179	+	1	1,687	974	152	–	+
	1958	1,955	2,348	40	+	+	584	776	29	–	+
	1959	1,767	2,491	162	+	2	385	738	54	+	+
	1960	925	836	42	+	1	208	213	15	–	+
	Sub-total	9,703	10,330	492	+	5	5,886	8,637	305	+	1
June	1955	3,390	6,028	4,074	4	5	551	1,200	447	+	1
	1956	150	204	113	+	+	1,724	3,285	184	3	3
	1957	3,780	2,435	4,289	8	1	1,114	618	1,328	+	1
	1958	4,326	4,750	3,491	4	12	737	1,301	187	+	2
	1959	2,416	3,969	5,172	31	7	1,307	2,048	2,020	5	4
	1960	1,071	1,480	443	1	3	1,001	520	39	–	2
	Sub-total	15,133	18,866	17,582	48	28	6,434	8,972	4,205	8	13
July	1955	2,560	2,980	7,701	513	12	60	56	75	+	+
	1956	1,375	1,513	9,912	1,584	36	737	238	163	1,467	22
	1957	3,398	1,053	11,078	331	8	–	–	–	–	–
	1958	3,414	5,773	8,826	1,660	18	–	–	–	–	–
	1959	1,591	1,521	1,885	800	17	100	160	81	554	2
	1960	5,563	3,198	301	433	19	590	202	13	505	14
	Sub-total	17,901	16,038	39,703	5,321	110	1,487	656	332	2,526	38
Aug.	1955	1,426	1,800	1,870	2,178	42	–	–	–	–	–
	1956	1,178	1,191	1,352	690	18	–	–	–	–	–
	1957	–	–	–	–	–	–	–	–	–	–
	1958	802	1,936	622	1,587	13	151	284	6	89	1
	1959	–	–	–	–	–	–	–	–	–	–
	1960	144	48	4	13	1	25	4	+	2	+
	Sub-total	3,550	4,975	3,848	4,468	74	176	288	6	91	1
Bering Sea											
May	1957	–	–	–	–	–	364	258	1	–	+
	Sub-total	–	–	–	–	–	364	258	1	–	+
June	1956	–	–	–	–	–	1,606	2,704	86	+	35
	1957	–	–	–	–	–	5,430	1,121	2,703	+	15
	1959	–	–	–	–	–	295	508	724	+	2
	1960	29	112	191	–	6	2,984	3,056	660	+	117
	Sub-total	29	112	191	–	6	10,315	7,389	4,173	+	169
July	1956	271	620	1	+	+	358	1,838	10	1	12
	1957	72	23	357	+	+	145	154	960	+	+
	1959	179	346	1,275	4	1	1,085	1,075	7,485	30	28
	1960	66	166	330	–	3	83	616	32	+	16
	Sub-total	588	1,155	1,963	4	4	1,671	3,683	8,487	31	56
Aug.	1960	–	–	–	–	–	190	36	3	8	–
	Sub-total	–	–	–	–	–	190	36	3	8	–

Continued . . .

Table 48. Continued.

		West of 170 E					East of 170 E				
		Sockeye	Chum	Pink	Coho	Chinook	Sockeye	Chum	Pink	Coho	Chinook
Okhotsk Sea											
June	1955	33	1,485	1,351	1	1					
	1956	27	1,037	570	–	+					
	1957	32	1,565	2,162	+	+					
	1958	12	953	1,050	+	+					
	Sub-total	104	5,040	5,133	1	1					
July	1955	124	1,310	5,683	43	+					
	1956	566	2,144	4,129	105	+					
	1957	243	1,096	4,672	102	+					
	1958	33	585	1,058	24	+					
	Sub-total	966	5,135	15,542	274	+					
Aug.	1955	143	166	1,580	313	1					
	1956	64	44	668	13	–					
	1957	–	–	–	–	–					
	1958	9	84	240	27	+					
	Sub-total	216	294	2,488	353	1					

In June, with fishing being conducted in the Bering Sea and the Okhotsk Sea as well as in the North Pacific, the total catch in this month annually was considerably larger than in May.

In the North Pacific west of Longitude 170°E, pink salmon increased in numbers from May, and as a result the relative importance of chum and sockeye salmon declined. The chum salmon, nevertheless, considering the catch for combined years, was still the dominant species, but in individual years was superseded by the pink salmon in 1957 and 1959. Sockeye salmon ranked second in relative importance in 1956, 1957, 1958 and 1960. The catches of coho and chinook salmon, while slightly larger than in May, were still small.

In the North Pacific east of Longitude 170°E, although the catch for all years combined was smaller than that in the western region, as in the latter region chum salmon dominated. In individual years, however, chum salmon ranked first in 1955, 1956 and 1958; sockeye in 1960; pink salmon in 1957. In 1959, chum and pink salmon were almost equal and of primary importance.

In the Bering Sea in June, during the four years of fishing (1956, 1957, 1959, 1960), catches in each year but 1960 were exclusively made in the region east of Longitude 170°E. Sockeye salmon ranked first in the combined annual catches, followed by chum, pink, chinook and coho salmon, in that order. Similar to the North Pacific region east of Longitude 170°E, chinook salmon catches exceeded coho salmon catches. In individual years, however, sockeye dominated in 1957 only, chum salmon in 1956 and 1960 and pink salmon in 1959.

In the Okhotsk Sea in June, the total salmon catch in each year was very much smaller than in either the North Pacific or the Bering Sea, and consisted largely of pink and chum salmon, the species composition of salmon thus differing from that in other regions. Sockeye, coho and chinook salmon were also caught but in very low numbers. Chum salmon dominated the catches in 1955 and 1956; pink salmon in 1957 and 1958.

In July in the North Pacific, as the fishery shifted westward, the catches west of Longitude 170°E increased while those east of Longitude 170°E decreased. In the region west of Longitude 170°E, the relative importance of the individual species changed further since June. In general, pink salmon were largely dominant, especially in the earlier years. The catch of pink salmon in 1960, however, was very small, the species ranking fourth in importance and being surpassed by all but chinook salmon. Coho salmon catches in all years were very high in July compared to June, with the best years being 1956, 1958 and 1959, in that order. The chum salmon and the sockeye salmon, except the latter in 1960 when it was the dominant species, generally were relatively less important than in June. Chinook salmon catches

ere low in all years, although much improved over ne.

In the region east of Longitude 170°E, fishing was rried out sporadically instead of each year. Con-dering the four years of fishing (1955, 1956, 1959, 960) collectively, the coho salmon preceded all other ecies in importance and ranked first in the catches r 1956 and 1959. This is in marked contrast to ne when, in the presence of considerably more shing effort, coho salmon catches were very small.

In the Bering Sea in July, as in the North Pacific, ie fishery shifted westward, but unlike the North acific, total salmon catches continued to be larger st of Longitude 170°E, where effort was greater, an west of Longitude 170°E. In each year but 960, the species composition pattern in the two gions was quite similar. In 1956, the chum salmon rgely dominated the catch. In 1957 and 1959, ie pink salmon was by far the most important species. n 1960, however, pink salmon were dominant only est of Longitude 170°E, while chum salmon ranked rst east of Longitude 170°E. Sockeye salmon in ach year were relatively unimportant (although ver one million were caught in 1959), as were coho nd chinook salmon.

In the Okhotsk Sea in July, catches were larger han in June, mainly as a result of the increased umbers of pink salmon, the species which dominated he catch in each year (1955–1958). Chum salmon vere relatively less important in July than in June, but ockeye and coho salmon, although not particularly umerous in the catches, showed significant increases ince June. Chinook salmon formed negligible frac-ions of the catch in each year.

Information on the relative importance of the almon species by region in August is much less complete than for either June or July.

In the North Pacific in August, fishing occurred n four of the six years (1955, 1956, 1958 and 1960) nd mainly west of Longitude 170°E. Fishing effort n each year was much reduced from July, resulting n very much smaller catches. The most outstanding eature was the declining importance of pink salmon and the increasing importance of coho salmon. In 1955, when the fishing season ended in late August and was the latest in any year, coho salmon dominated the catches. The relative importance of chum and sockeye salmon on the other hand was quite variable. Chum salmon dominated the catch in 1958, sockeye salmon in 1960.

In the Okhotsk Sea, August catches were consider-ably smaller than those of July. Pink salmon in each year constituted a large portion of the catch, larger than in the North Pacific. Coho salmon also were relatively more important in August than in July.

B. According to INPFC Research Vessel Operations

As stated earlier, information on the relative importance of the individual Pacific salmon species in all regions of the North Pacific and the Bering Sea can be obtained only by examining research vessel catch data. The data used for this purpose are the monthly mean regional relative abundance indices (weighted catch per 3,000 feet of standard INPFC gillnet) for the individual species from 1955 to 1960. The indices for each species are shown in Table 49. For each month and region, the species and their indices are listed in order of magnitude of catch per unit of effort, with the highest value appearing as the left hand entry in each row. To avoid the effect of negative catches in waters too far south for salmon, in the late season only those fishing operations along Latitude 48°N and north were considered. In the central and eastern areas of the Gulf of Alaska, where salmon do not occur as far south as in other regions to the west, the latitudinal boundary was set at 50°N. Further, to minimize variability caused by a paucity of observations, only mean indices based on five or more fishing operations were considered. The data falling into this category are signified in the table. Since chinook salmon generally were extremely relatively scarce in the catches, they are not included in the table.

Some indication of the regional variations in the total salmon population in each month from May to August or September can be obtained by examining Figure 35, which shows the sums of the individual species indices based on five or more observations. In most years for which there are data, it is suggested that salmon tended to be more numerous in the western regions of the North Pacific than in the eastern regions. This tendency is borne out if indices for the same month in different regions are compared, and is especially notable in 1956 and 1957, 1958 and 1959, with either the Southeast Kamchatka-Southwest Aleutian or the Aleutian regions being the most important. Since large quantities of salmon annually were removed from the northwest Pacific through commercial fishing, the disparity in the relative numbers of salmon in the western and eastern regions of the North Pacific was presumably even greater than indicated.

TABLE 49. Average regional catch per unit of effort (3,000 feet of INPFC gillnet) of salmon by research vessels, by month for individual years, 1955–1960. (S=sockeye, C=chum, P=pink, Co=coho.)

	May	June	July	August	September
Southeast Kamchatka-Southwest Aleutian					
1955	—	—	C(12) P(11) S(8)	C(20) S(12) Co(6) P(1)	—
1956	C(20) S(2)	*C(32) S(11) P(3)	*S(33) C(15) Co(5)	*S(23) C(12) Co(2) P(1)	—
1957	*S(20) C(12) P(3)	*P(70) C(10) S(10)	*C(24) S(19) P(9) Co(4)	*S(21) C(19) Co(7) P(1)	—
1958	*C(8) S(1)	*C(5) S(3) P(2)	S(31) C(12) Co(2)	*S(22) C(10) Co(3)	—
1959	S(5) C(3)	S(5) C(3)	S(6) C(4) P(1)	*S(15) C(6) Co(6)	—
1960	S(9) C(6) P(1)	*S(9) C(9) P(3)	S(35) C(35) Co(1)	*S(16) C(12) Co(3)	—
Aleutian					
1955	*C(48) S(18) P(1)	*P(28) C(20) S(9)	—	*C(10) S(9)	*C(23) S(8)
1956	*S(4) C(4) P(1)	*C(17) S(11) P(3)	—	*S(20) C(11)	C(4)
1957	P(40) C(10) S(2)	*P(33) S(12) C(10)	*C(32) S(4) Co(3) P(1)	*S(30) C(13) Co(1)	—
1958	*C(5) S(2) P(2)	*C(60) S(8)	*C(20) S(8) Co(2) P(1)	*C(30) S(20) Co(2)	—
1959	*C(25) S(16) P(3)	*S(18) C(14) P(10)	*S(72) C(20) P(10) Co(5)	*S(49) C(8)	—
1960	*S(12) C(8) P(3)	*S(23) C(12) P(2)	*C(37) S(31) P(2) Co(2)	*S(51) C(11)	—
Western Gulf					
1955	—	—	*S(11) C(7) P(3) Co(1)	*C(18) S(15) P(1)	S(5) C(2)
1956	S(9) C(7)	S(1) C(1)	*C(11) S(10) P(3)	*C(12) S(1)	*C(7) S(2)
1957	—	S(9) C(1) Co(1) P(1)	*C(12) S(10) Co(1) P(1)	*C(30) S(2)	—
1958	—	*S(20) C(5)	—	*C(11) S(5) P(1)	—
1959	C(6) S(2)	*S(30) C(11) P(9)	*S(42) C(33) P(5) Co(1)	S(5) C(1) P(1)	—
1960	—	—	—	C(3) S(1) P(1)	—
Central Gulf					
1955	—	—	*C(11) P(9) S(4) Co(2)	*C(10) S(4) P(1)	C(15) S(1)
1956	S(7) C(4) P(1)	S(6) P(3) Co(3) C(1)	*C(12) S(4) P(3) Co(1)	*C(8) S(2) P(1)	*C(4) S(1)
1957	—	*C(10) S(4) P(2) Co(2)	*P(6) S(5) C(1)	C(4)	—
1958	S(5) C(4) P(2)	*S(11) C(2) P(1)	S(1)	*C(2)	—
1959	*S(11) C(4) P(1)	—	*S(8) C(6) P(4)	—	—
1960	—	—	—	—	—
North Coastal Gulf					
1955	—	—	Co(15) C(10) P(9) S(7)	*P(13) C(10)	C(29) P(1)
1956	C(1)	—	*C(8) P(8) S(3) Co(3)	P(22) C(8) S(3)	—
1957	—	—	S(7) C(6) P(4) Co(1)	C(30) S(1)	C(4)
1958	—	S(20) C(22) P(5)	—	C(2)	—
1959	S(18) C(2)	—	—	—	—
1960	—	—	—	—	—
South Coastal Gulf					
1955	—	S(2) C(1) P(1)	C(2) Co(1) S(1)	—	Co(2) C(1)
1956	S(2) C(1) Co(1) P(1)	C(12) Co(3) S(1)	*C(2) S(1) P(1)	*S(1) P(1)	—
1957	*C(2) S(1)	C(28) Co(8) S(7) P(3)	S(11) P(2) C(1)	S(1)	—
1958	—	—	—	—	—
1959	—	—	*S(5)	—	—
1960	—	—			

Continued

Table 49. Continued

	May	June	July	August	September
Western Bering Sea					
1955	—	—	*S(15) C(15) P(10)	*C(32) S(28) Co(2)	—
1956	—	—	*C(38) S(23)	*C(20) S(12) P(2)	—
1957	—	—	P(130) S(40) C(22)	—	—
1958	S(3) C(1) P(1)	*P(10) C(4) S(3)	C(30) S(6) P(1)	*S(30) C(22)	—
1959	—	S(13) C(11) P(2)	C(50) P(20) S(5)	*S(20) C(18) P(1) Co(1)	—
1960	—	*P(10) C(9) S(8)	*C(87) S(27)	*C(23) S(15)	—
Central Bering Sea					
1955	S(1) C(1)	*C(13) S(9) P(6)	*C(32) P(8) S(3)	C(88) S(9)	—
1956	—	*C(9) S(9) P(1)	*C(32) S(5)	C(4) S(1)	—
1957	—	*P(64) S(35) C(10)	*C(41) S(5) P(2)	*C(15) S(11)	—
1958	S(4) C(1) P(1)	*C(8) S(5) P(1)	*C(39) S(3) P(1) Co(1)	C(5) S(1)	—
1959	—	*P(20) S(12) C(8)	*P(20) C(19) S(5)	—	—
1960	—	*S(26) C(8) P(2)	S(6) C(4)	—	—
Eastern Bering Sea					
1955	—	*S(28) C(9) P(1)	—	—	—
1956	—	*S(68) C(18) P(1)	S(1) C(1) Co(1)	*C(2) S(1)	*C(1)
1957	—	*S(40) C(2) P(2)	*C(5) S(5) Co(1) P(1)	S(1)	—
1958	—	*S(8) C(1)	—	—	—
1959	—	S(22) C(10) P(8)	—	—	—
1960	—	S(43) C(18) P(1)	—	—	—

* Values based on five or more fishing operations.

In the Bering Sea, the relative size of the salmon population in the three regions varied seasonally. Although adequate indices are few, it appeared that salmon were more numerous in the Central, especially, and Western Bering Sea regions than in the Eastern Bering Sea region. This apparent difference in numbers increased from May to August, and westward. Exceptions to this tendency were June of 1956 and possibly of 1955, when salmon were more numerous in the Eastern than in the Central Bering Sea region.

In both the North Pacific and the Bering Sea, the relative importance of the individual salmon species varied regionally and monthly in each year. Considering Table 49, in May, salmon collectively were relatively more numerous in the North Pacific than in the Bering Sea regions. The total salmon population, as indicated by catches, in each year apparently consisted largely of chum and sockeye salmon, their rank in importance not necessarily being in that order and differing between years and regions. An apparent exception to this tendency of annual variations in species dominance was the Central Gulf of Alaska region where the sockeye salmon was the dominant species in three years of fishing (1956, 1958 and 1959).

In June, as relative numbers of salmon increased generally, chum and sockeye salmon continued to rank either first or second in importance in each region. In some regions, however, pink salmon were becoming more numerous and, as a consequence, the relative importance of all other species declined. This is especially the case in the Southeast Kamchatka-Southwest Aleutian, Aleutian and Western Bering Sea regions, where in some years, usually odd-numbered, pink salmon outranked all other species in relative numbers. Sockeye salmon annually dominated in the Western Gulf of Alaska region, immediately to the west of the region where they were consistently dominant in May, and in the Eastern Bering Sea region, chum salmon ranking second.

In July, the different species varied considerably in their relative importance and in no single region did a particular species dominate in all years of fishing. Sockeye and chum salmon were still relatively more numerous than any other species, especially in the Aleutian and Western Gulf of Alaska regions of the North Pacific and in the Bering Sea where usually the relative numbers of pink salmon had declined since June. Also during July, coho salmon increased in relative importance and in some regions (Aleutian

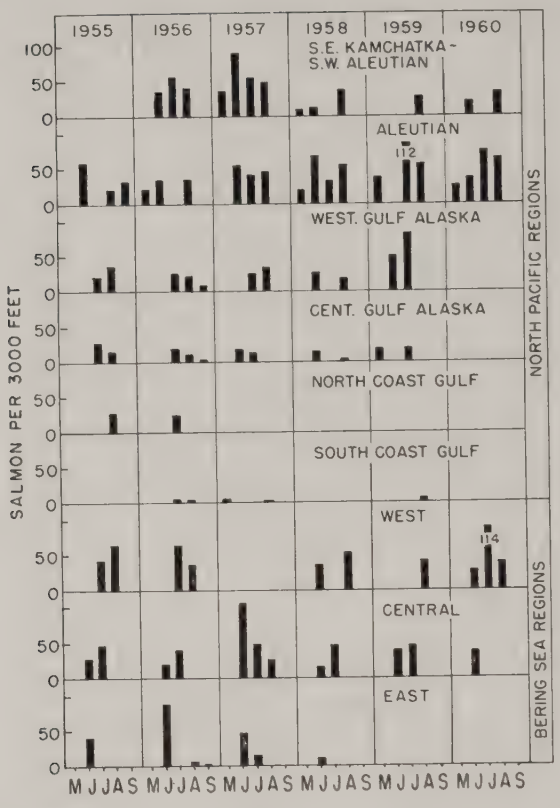

FIGURE 35. Mean monthly relative abundance indices of salmon in the North Pacific and Bering Sea as shown by research vessels, 1955–1960. Indices are based on five or more observations.

region in 1957, 1958; Western Gulf of Alaska in 1957) ranked third, following sockeye and chum salmon. It is not until July that coho salmon occur in numbers in the Bering Sea.

In August, the evacuation of the high seas by maturing individuals being virtually completed, salmon were relatively less abundant than in July. In the Southeast Kamchatka-Southwest Aleutian region, sockeye salmon ranked first in every year fished but one. Elsewhere, chum salmon in most years outranked all other species in importance, especially in the Western and Central Gulf of Alaska regions. Pink salmon, in all regions, were relatively unimportant, while coho salmon were even more important than in July. This was particularly notable in the Southeast Kamchatka-Southwest Aleutian region. Limited and sporadic fishing in September in the North Pacific indicated the chum salmon to be the dominant species, usually followed by the sockeye salmon.

C. Summary

Mothership catches and catch per unit of effort indices for research vessels showed that the individual species of salmon varied in relative importance annually, seasonally and regionally. These variations can be accounted for by differences in yearclass strengths of the various salmon stocks, within as well as between species, by differences in the migration patterns of maturing and immature individuals, and by changing environmental conditions. In spite of these variations, however, it would appear that the importance of one species compared with another through the season follows a basic pattern which is common to most years.

In May, in the North Pacific, salmon were most abundant in waters some distance southwest from the western Aleutians, and south of the central Aleutians. Sockeye and chum salmon formed almost the entire salmon catch of both commercial and research vessels, indicating that these species were very numerous in relation to other salmon species. Neither of these two species dominated the catch in all years. Chum salmon, however, did tend to surpass sockeye salmon in importance in most years. In areas to the west and east of this large, relatively dense concentration of salmon, the availability of salmon progressively declined. According to research vessel data, south of the Alaska Peninsula either sockeye or chum salmon ranked first in importance, but in the Gulf of Alaska sockeye salmon annually dominated the catches.

According to limited information from research vessels, in the southern sector of the Bering Sea, salmon, consisting largely of sockeye, were relatively most numerous in the central areas.

Positive information on the relative size of the salmon population or the species composition in May in the Okhotsk Sea was not available, but judging from catches for the region in June, and from those in the waters approaching southeast Kamchatka in May, it would appear that salmon were not particularly abundant. Also, the chum salmon probably was more numerous than any of the other species.

In June, salmon generally were more available than in May, this being reflected in both commercial and research vessel operations. The size of the total population in the North Pacific decreased from west to east. In the regions west of the Gulf of Alaska, sockeye and chum salmon continued to be dominant, not necessarily in that order in each year, but their importance declined somewhat through the month

; pink salmon formed an increasingly larger fraction f the catches. In the Western Gulf of Alaska region, shing by research vessels showed that sockeye salmon ominated.

In the Bering Sea, salmon were relatively most bundant in the central or eastern areas. Sockeye almon annually dominated in the Eastern Bering Sea egion and were followed by chum salmon. Pink almon increased in numbers, particularly westward. his feature regarding pink salmon was more apparent odd-numbered than in even-numbered years. oho salmon were virtually absent, while chinook almon were present in relatively small numbers.

In the Okhotsk Sea, the salmon population consisted largely of chum and pink salmon.

In July, mothership and research vessels operating n the North Pacific indicated that salmon were relatively most numerous off southeast Kamchatka and he western Aleutian Islands. Corroboratory evidence from these two types of operations regarding the importance of different species was not as good as in May and June. Mothership catches showed that pink and coho salmon both increased in importance since June, pink salmon being dominant in the northwest Pacific in all years but one (1960). The salmon population south of the Aleutians apparently was smaller than to the westward and coho salmon in some years (1956, 1959) outnumbered all other species n the catches. Research vessels, on the other hand, also revealed the increasing importance of coho salmon, but also showed that either sockeye or chum salmon were relatively most abundant. The difference in fishing results for mothership and research vessels presumably was caused by the differences in the gillnets used by each; research vessels employed smaller meshed gillnets and hence were more able to capture relatively more of the increasing numbers of smaller, younger sockeye and chum salmon as these became more available. In the Gulf of Alaska, according to research vessels, either sockeye or chum salmon dominated in the catches, frequently followed by pink salmon. Coho salmon were relatively more important than in June as their numbers increased and matures of other species evacuated the high seas areas.

In the Bering Sea, especially in the Central and Western regions, where, according to research vessel data, salmon were most abundant, either pink (usually in odd-numbered years) or chum salmon dominated.

In the Okhotsk Sea, in July, pink salmon formed a very large fraction of the total salmon catch. Concomitantly, chum salmon declined in importance and sockeye and coho salmon increased.

In August in the North Pacific, the trend regarding species composition noted for July continued. Coho salmon increased further in importance, pink salmon declined, and either sockeye or chum salmon, virtually all immature, dominated. Salmon as a whole were much more numerous in the western areas of both the North Pacific and the Bering Sea. In the Okhotsk Sea, in contrast to either the North Pacific or Bering Sea, pink salmon dominated in the total salmon population, which according to commercial fishing during the early portion of the month, was relatively smaller than in July.

ACKNOWLEDGMENT

The authors are indebted to many individuals and groups in Canada, Japan and the United States who have contributed much in many ways to this report. They are especially grateful to Mr. M. P. Miyake of the Japanese Fisheries Agency, who principally and ably acted as interpreter during meetings in Japan, but who was also helpful professionally, and to Miss V. Coleman for useful suggestions for illustrating some of the data and for preparing all figures.

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CONVERSION FACTORS FOR LENGTHS

1 meter = 0.001 kilometers
= 100 centimeters
= 1000 millimeters
= 0.547 fathoms
= 3.28 feet
= 39.37 inches
= 3.31 shaku
= 33.14 sun.

APPENDIX TABLE A. HIGH SEAS SALMON CATCHES BY INPFC GILLNET RESEARCH VESSELS, 1955–1960

(Number of gillnets of varying mesh sizes fished and their catches are given by actual position of set, along with surface water temperature (°C) and fishing time. Within each year, tables are arranged by country in the order of Canada, Japan and the United States.)

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A-1. 1955, Tsukiyama-maru (Japan)

Date		Lat. (°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	Number of tans[1] of varying mesh size[2]					Sockeye					
						5.4	4.8	4.2	3.6	3.0	5.4	4.8	4.2	3.6	3.0	Total
May	21	45—40	170—55 E	13	5.4	30	20	20	20	10	81	39	62	16	2	200
	22	46—39	171—58 E	13	5.4	30	20	20	20	10	8	11	19	11	1	50
	25	48—41	176—12 E	13	4.2	30	20	20	20	10	48	31	26	7	1	113
	26	49—42	177—36 E	13	4.5	30	20	20	20	10	42	39	30	1	1	113
	28	52—14	176—18W	12	4.5	30	20	20	20	10	—	1	—	—	1	2
June	2	50—43	177—18W	13	4.8	30	20	20	20	10	21	14	7	2	—	44
	3	49—50	175—55W	13	4.9	30	20	20	20	10	24	34	11	7	1	77
	4	48—46	175—01W	13	5.0	30	20	20	20	10	6	9	10	1	—	26
	5	47—54	174—14W	12	5.2	30	20	20	20	10	3	8	19	7	—	37
	6	49—06	173—49W	13	5.4	30	20	20	20	10	3	11	11	3	—	28
	7	50—16	173—26W	13	5.2	30	20	20	20	10	13	17	13	1	—	44
	8	51—11	173—03W	13	5.2	30	20	20	20	10	29	19	11	8	3	70
	9	51—08	171—31W	13	5.5	30	20	20	20	10	60	51	38	21	4	174
	10	50—35	170—40W	13	5.9	30	20	20	20	10	14	4	12	4	—	34
	11	49—49	169—34W	12	6.4	30	20	20	20	10	2	1	—	3	—	6
	12	48—45	168—33W	13	6.4	30	20	20	20	10	4	4	10	2	—	20
	13	49—58	168—21W	13	6.1	30	20	20	20	10	7	5	7	3	1	23
	14	51—30	168—24W	13	5.9	30	20	20	20	10	7	8	—	1	2	18
	15	52—24	169—22W	12	6.0	30	20	20	20	10	68	45	10	4	2	129
	17	54—12	169—24W	13	5.9	30	20	20	20	9	180	119	125	41	7	472
	18	54—16	169—19W	13	5.7	30	20	20	19	9	63	40	15	21	10	149
	19	54—59	171—42W	13	5.1	30	20	20	19	9	11	8	13	1	1	34
	22	57—06	172—56W	13	4.6	30	20	20	19	9	136	38	24	7	—	205
	23	57—37	171—25W	12	4.4	30	20	20	19	9	4	—	1	—	—	5
	24	58—12	169—37W	12	3.8	30	20	20	19	9	3	3	6	1	—	13
	25	59—09	168—56W	13	2.1	30	20	20	19	9	—	1	—	—	—	1
	27	55—46	167—48W	13	6.0	30	20	20	19	9	129	97	57	10	1	294
	29	54—07	173—12W	11	5.5	30	20	19	19	9	2	2	2	1	—	7
	30	54—08	175—24W	12	5.4	30	20	19	19	9	21	15	16	1	—	53
July	1	54—06	177—49W	11	5.4	30	20	19	19	9	22	13	5	—	—	40
	2	53—57	179—54 E	13	5.7	30	20	19	19	9	7	8	4	4	—	23
	14	54—02	169—54 E	12	5.9	30	20	19	19	9	14	17	29	24	55	139
	15	52—32	169—58 E	11	6.2	30	20	19	19	9	12	9	18	6	3	48
	16	57—05	169—46 E	12	6.1	30	20	19	19	9	1	8	11	21	8	49
	17	56—57	172—21 E	12	6.6	30	20	19	19	9	6	2	5	7	11	31
	18	57—05	174—29 E	13	6.2	30	20	19	19	9	7	6	6	3	2	24
	19	57—06	176—28 E	11	6.0	30	20	19	19	9	4	4	5	3	4	20
	20	57—01	178—34 E	11	6.0	30	20	19	19	9	4	3	3	2	—	12
	21	57—05	179—15W	10	6.4	30	19	19	19	9	1	—	—	—	—	1
	23	57—04	174—04W	12	7.2	30	19	19	19	9	—	1	—	—	—	1
	24	57—01	171—58W	11	7.5	30	19	19	19	9	—	—	—	—	—	—
	25	58—01	172—04W	12	7.9	30	19	19	19	9	—	—	—	—	—	—
	26	58—59	172—04W	12	7.5	30	19	19	19	9	—	—	—	—	—	—
	27	59—57	171—58W	12	4.8	30	19	19	19	9	—	—	—	—	—	—
	29	60—02	174—25W	12	7.0	29	19	19	19	9	—	1	1	—	—	2
	30	59—57	176—36W	11	7.4	29	19	19	19	9	—	—	—	—	—	—
	31	60—07	179—06W	12	6.9	29	19	19	19	9	11	10	11	23	51	106
Aug.	1	60—05	178—45 E	12	7.1	29	19	19	19	9	5	6	18	21	23	73
	2	60—01	176—28 E	13	7.4	29	19	19	19	9	9	12	16	25	15	77
	4	60—02	174—06 E	12	7.5	29	19	17	19	9	32	39	39	24	12	146
	5	59—29	172—04 E	11	7.6	29	19	17	19	9	21	20	18	38	22	119
	6	59—03	169—39 E	13	7.9	29	19	17	19	9	23	25	25	39	19	131
	7	58—59	167—49 E	12	8.8	29	19	17	19	8	35	36	38	50	27	186
	8	58—12	166—18 E	12	9.2	29	19	17	19	8	25	20	30	30	20	125
	9	57—11	165—16 E	12	11.0	29	19	18	19	8	22	25	21	17	23	108
	10	56—06	164—31 E	11	10.6	29	19	17	19	8	19	17	29	29	11	105
	12	53—13	162—29 E	12	10.1	29	19	17	19	8	15	10	11	4	5	45
	13	52—31	161—37 E	13	11.6	98	40	17	—	—	92	49	31	—	—	172
	14	52—11	161—14 E	14	13.0	98	55	17	—	—	97	71	27	—	—	195
	16	51—48	160—32 E	11	11.0	61	36	—	—	—	107	108	—	—	—	215

[1] Length of one tan is 180 feet.

[2] Mesh size in sun (see conversion factors, p. 129).

Chum						Pink						Coho						Chinook					
4	4.8	4.2	3.6	3.0	Total	5.4	4.8	4.2	3.6	3.0	Total	5.4	4.8	4.2	3.6	3.0	Total	5.4	4.8	4.2	3.6	3.0	Total
5	23	32	50	11	131	4	5	54	132	—	195	—	—	—	—	—	—	—	—	—	—	—	—
23	11	64	42	1	141	—	7	29	58	2	96	—	—	—	—	—	—	—	—	—	—	—	—
22	46	106	70	2	246	1	4	5	2	—	12	—	—	—	—	—	—	—	—	—	—	—	—
48	51	130	105	5	339	—	1	—	1	—	2	—	—	—	—	—	—	—	—	—	—	—	—
—	5	—	—	—	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
31	30	27	23	—	111	3	4	7	2	—	16	—	—	—	—	—	—	—	—	—	—	—	—
31	48	56	38	—	173	27	95	140	159	10	431	—	—	—	—	—	—	—	—	—	1	—	1
7	20	24	13	1	65	1	17	24	86	2	130	—	—	—	—	—	—	—	—	—	1	—	1
2	18	16	30	—	66	—	5	—	21	6	32	—	—	—	—	—	—	—	—	—	—	—	—
10	29	52	51	—	142	4	47	120	233	3	407	—	—	—	—	—	—	—	—	—	—	—	—
9	24	62	66	—	161	25	71	68	57	3	224	—	—	—	—	—	—	—	—	—	—	—	—
6	4	23	15	—	48	25	51	71	34	—	181	—	—	—	—	—	—	—	—	—	—	—	—
28	39	48	49	—	164	28	28	55	29	1	141	—	—	—	—	—	—	—	1	—	—	—	1
2	3	25	21	1	52	9	16	123	80	6	234	—	—	—	—	—	—	—	—	—	—	—	—
13	20	17	43	3	96	25	66	80	40	—	211	—	—	—	—	—	—	—	—	—	—	—	—
13	44	152	204	15	428	1	14	56	41	5	117	1	—	—	—	—	1	—	—	—	—	—	—
5	4	8	18	1	36	3	19	14	18	1	55	—	—	—	—	—	—	—	—	—	—	—	—
5	36	56	47	—	144	5	14	20	11	—	50	—	—	—	—	—	—	—	—	—	—	—	—
7	43	13	4	—	67	3	4	2	—	—	9	—	—	—	—	—	—	—	—	—	—	—	—
47	49	49	14	—	159	2	4	6	—	—	12	—	—	—	—	—	—	1	1	—	—	—	2
21	26	33	18	—	98	2	2	4	9	—	17	—	—	—	—	—	—	—	2	—	2	—	4
1	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
48	39	6	1	—	94	2	2	3	1	—	8	—	—	—	—	—	—	—	—	—	—	—	—
2	—	—	1	—	3	—	—	—	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—
3	5	—	—	—	8	—	1	1	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—
2	8	—	—	—	10	—	—	—	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—
3	3	2	1	—	9	1	—	1	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—
—	1	3	5	—	9	—	—	1	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
40	35	113	78	1	267	13	43	47	30	1	134	—	—	—	—	—	—	—	—	—	—	—	—
26	20	62	18	—	126	9	16	72	35	1	133	—	—	—	—	—	—	—	—	—	—	—	—
15	12	5	10	4	46	10	25	41	17	—	93	—	—	—	—	—	—	—	—	—	—	—	—
37	31	42	32	3	145	7	12	7	6	2	34	—	—	—	—	—	—	—	—	—	—	—	—
10	22	30	15	5	82	7	10	32	16	—	65	—	—	—	—	—	—	—	—	—	—	—	—
47	43	17	7	6	120	25	15	68	62	1	171	—	—	—	—	—	—	—	—	—	—	—	—
16	9	4	1	—	30	7	10	21	5	—	43	—	—	—	—	—	—	—	—	—	—	—	—
30	26	19	4	1	80	5	8	14	13	—	40	—	—	—	—	—	—	—	—	1	3	—	4
62	75	141	55	29	362	4	6	17	6	—	33	—	—	—	—	—	—	—	—	—	—	—	—
75	113	166	134	31	519	2	2	5	2	1	12	—	—	—	—	—	—	—	1	—	—	—	1
4	8	17	48	16	93	—	1	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
1	1	2	1	—	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	12	—	—	—	15	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	—	1	—	—	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	1
16	26	6	3	—	51	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1	—	2	—	—	3	—	—	1	—	—	1	—	—	—	1	—	1	—	—	1	—	—	1
8	2	8	—	2	20	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	1
17	91	304	241	244	997	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	1
35	40	143	67	37	322	—	—	—	—	—	—	—	1	—	—	—	1	2	1	1	1	—	5
74	124	154	99	73	624	—	—	—	—	—	—	—	—	1	—	—	1	3	1	3	17	2	26
13	112	95	39	85	444	—	—	—	—	—	—	2	—	—	—	—	2	1	—	1	—	1	3
43	36	22	38	21	160	—	—	—	1	—	1	3	—	—	—	—	3	—	—	—	1	—	1
42	21	22	7	12	104	—	1	2	—	—	3	5	2	—	—	—	7	—	—	—	—	—	—
41	36	37	26	31	171	—	2	1	—	—	3	5	7	4	—	—	16	—	—	1	2	—	3
18	18	13	19	38	106	1	—	—	—	—	1	11	3	1	1	—	16	—	—	—	—	—	—
18	9	8	19	13	67	1	2	—	1	—	4	6	3	2	1	—	12	—	—	—	—	—	—
12	5	7	12	5	41	—	2	—	—	—	2	3	2	2	—	—	7	—	—	—	—	—	—
17	13	10	11	9	60	1	1	—	—	—	2	69	55	10	3	1	138	—	—	—	—	—	—
155	50	16	—	—	221	13	3	2	—	—	18	127	29	8	—	—	164	2	—	—	—	—	2
132	206	90	—	—	728	6	2	1	—	—	9	48	22	11	—	—	81	—	—	—	—	—	—
86	57	—	—	—	143	2	4	—	—	—	6	8	6	—	—	—	14	—	1	—	—	—	1

A-2. 1955, John N. Cobb (U.S.)

Date	Lat. (°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of shackles of varying mesh size[1]				Sockeye				
					2½	3¼	4½	5¼	2½	3¼	4½	5¼	Total
June 26	49—29	131—29W	8.7	10.0	—	4	5	3	—	—	1	1	2
27	51—02	132—52W	8.5	10.0	—	4	5	3	—	1	2	2	5
July 1	53—17	135—42W	8.0	9.4	—	4	5	3	—	—	—	—	–
2	53—40	134—26W	7.0	10.1	—	2	2	—	—	—	1	—	1
3	54—55	135—44W	11.2	9.4	—	4	5	3	—	1	3	3	7
4	55—55	136—08W	9.2	10.0	—	4	5	3	—	1	5	4	10
7	56—42	136—53W	10.2	11.1	—	2	5	3	—	1	1	—	2
8	57—40	137—37W	11.0	10.0	—	4	5	3	—	1	12	1	14
12	57—44	139—09W	8.7	10.0	—	2	5	11	—	—	11	19	30
13	57—35	141—21W	11.0	10.8	—	2	5	11	—	—	4	7	11
14	57—26	143—26W	10.5	10.6	—	2	5	11	—	2	8	8	18
15	57—18	145—28W	8.7	9.4	—	2	2	3	—	—	1	1	2
16	57—03	148—19W	5.7	9.1	—	2	2	3	—	—	1	—	1
17	57—01	149—32W	10.5	9.6	—	2	5	11	—	3	5	8	16
18	56—11	151—07W	10.5	9.4	—	2	5	11	—	2	4	4	10
22	55—38	152—37W	11.0	12.2	—	2	5	11	—	1	6	1	8
23	54—30	152—49W	9.7	11.4	—	2	5	11	—	—	4	1	5
24	53—26	152—36W	10.5	10.6	—	2	5	11	—	—	8	1	9
25	53—38	154—44W	8.5	10.0	—	2	5	11	—	2	2	1	5
26	53—47	156—23W	9.5	10.1	—	2	5	11	—	—	16	6	22
27	53—28	158—45W	6.7	10.0	—	2	5	11	—	1	4	2	7
30	53—12	161—49W	9.5	9.7	—	2	5	11	—	8	5	6	19
31	52—39	163—12W	10.5	10.6	—	2	5	11	—	2	2	1	5
Aug. 1	52—14	165—21W	8.5	9.9	—	2	5	11	—	3	12	3	18
2	53—20	165—27W	8.7	10.3	—	2	5	11	—	23	13	11	47
5	53—43	160—35W	11.0	11.7	—	2	5	11	—	9	4	8	21
6	54—10	158—14W	9.0	11.7	—	2	2	3	—	4	5	2	11
10	57—23	150—09W	7.7	11.4	—	2	7	19	—	—	2	2	4
11	56—29	148—49W	9.2	11.9	—	2	7	19	—	1	7	5	13
12	56—29	146—22W	8.2	11.4	—	2	2	3	—	1	—	—	1
17	56—07	144—17W	5.7	11.7	—	2	4	16	—	1	1	—	2
18	56—13	142—30W	14.2	11.4	—	2	7	19	—	—	3	9	12
19	56—16	140—35W	9.2	11.1	—	2	7	19	—	—	—	—	–
20	56—17	138—39W	8.7	11.9	—	2	7	19	—	—	1	2	3
20*	56—18	138—37W	6.5	12.2	—	2	7	19	—	—	—	1	1
21	56—19	138—42W	10.2	12.2	—	2	7	19	—	—	—	—	
22	56—18	136—39W	8.7	11.9	—	2	7	19	—	—	—	2	2
22*	56—18	136—45W	6.2	12.2	—	2	7	19	—	—	—	—	–
23	56—20	136—48W	8.5	11.7	—	2	7	19	—	—	—	—	
27	55—30	135—16W	8.5	11.9	—	4	6	18	—	—	—	—	
29	55—11	136—52W	8.2	11.9	—	4	6	18	—	—	—	—	
30	55—01	139—17W	8.2	11.7	—	4	6	18	—	—	—	—	—
Sept. 6	57—39	137—37W	10.2	11.7	—	3	4	12	—	—	—	—	—
7	57—46	139—23W	10.7	11.1	—	3	4	12	—	—	—	—	—
8	57—36	141—22W	9.0	10.6	—	3	4	12	—	—	—	—	—
9	57—25	143—26W	10.2	10.0	—	3	4	12	—	—	—	—	–
10	57—16	145—30W	11.0	10.3	—	3	4	12	—	—	—	—	
10*	57—17	145—28W	7.7	10.0	—	3	4	12	—	—	—	2	2
12	56—00	142—43W	8.7	10.3	—	3	4	12	—	—	1	2	3
13	55—01	141—25W	9.7	10.3	—	3	4	12	—	—	—	—	

* Day set.

[1] Mesh size in inches.

Chum					Pink					Coho					Chinook
2 1/2	3 1/4	4 1/2	5 1/4	Total	2 1/2	3 1/4	4 1/2	5 1/4	Total	2 1/2	3 1/4	4 1/2	5 1/4	Total	Total
—															
—	1	—	—	1	—	—	1	—	1	—	—	—	—	—	—
—	—	—	1	1	—	1	—	—	1	—	—	1	—	1	—
—	—	—	1	1	—	—	1	—	1	—	—	—	—	—	—
—	—	1	—	1	—	—	—	—	—	—	—	1	—	1	—
—	1	11	2	14	—	—	5	—	5	—	—	11	3	14	—
—	1	3	2	6	—	—	8	1	9	—	2	14	5	21	—
—	—	1	1	2	—	—	5	1	6	—	—	41	25	66	—
—	—	4	3	7	—	—	5	1	6	—	1	2	2	5	—
—	1	19	25	45	—	—	17	12	29	—	—	7	9	16	—
—	—	14	19	33	—	—	20	12	32	—	2	1	2	5	—
—	1	10	37	48	—	—	34	19	53	—	—	—	2	2	—
—	—	1	—	1	—	—	—	1	1	—	—	1	—	1	—
—	—	4	2	6	—	—	—	—	—	—	—	—	—	—	—
—	—	26	38	64	—	—	16	22	38	—	—	—	5	5	2
—	—	20	41	61	—	—	6	11	17	—	1	—	1	2	1
—	—	4	6	10	—	—	7	3	10	—	—	3	3	6	—
—	—	8	8	16	—	—	3	3	6	—	—	1	1	2	1
—	—	4	5	9	—	1	3	5	9	—	—	—	2	2	1
—	—	2	4	6	—	—	2	3	5	—	—	—	—	—	2
—	—	9	9	18	—	—	4	3	7	—	—	1	1	2	—
—	—	1	—	1	—	—	—	—	—	—	—	—	—	—	—
—	—	4	4	8	—	—	1	1	2	—	—	1	—	1	—
—	—	2	1	3	—	—	1	1	2	—	—	—	5	5	—
—	4	2	7	13	—	—	—	—	—	—	—	—	—	—	—
—	—	4	7	11	—	—	5	3	8	—	—	—	1	1	1
—	7	30	31	68	—	—	—	—	—	—	—	—	4	4	1
—	—	—	1	1	—	—	—	2	8	—	—	—	—	—	—
—	3	14	60	77	—	—	10	22	32	—	—	4	19	23	4
—	5	20	25	50	—	—	—	7	7	—	—	1	2	3	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	4	4	2	10	—	—	—	1	1	—	—	—	1	1	—
—	—	6	13	19	—	—	2	8	10	—	—	—	—	—	—
—	2	7	26	35	—	—	5	11	16	—	—	—	2	2	—
—	3	16	62	81	—	—	3	31	34	—	—	—	1	1	1
—	—	1	9	10	—	—	3	8	11	—	—	—	—	—	—
—	—	2	13	15	—	—	4	24	28	—	—	—	1	1	—
—	1	1	23	25	—	1	27	103	131	—	—	—	—	—	—
—	—	—	3	3	—	—	1	3	4	—	—	—	—	—	—
—	—	1	9	10	—	—	15	51	66	—	—	—	1	1	—
—	—	2	6	8	—	—	—	12	12	—	—	—	1	1	—
—	—	10	33	43	—	—	—	1	1	—	—	—	—	—	—
—	14	10	12	36	—	—	—	—	—	—	—	—	—	—	—
—	—	—	11	11	—	—	—	4	4	—	—	—	—	—	—
—	2	26	111	139	—	—	—	—	—	—	—	—	1	1	—
—	7	31	37	75	—	—	—	—	—	—	—	—	—	—	3
—	5	8	19	32	—	—	—	—	—	—	—	1	1	2	—
—	4	4	7	15	—	—	—	—	—	—	—	—	—	—	—
—	—	1	4	5	—	—	—	—	—	—	—	—	—	—	—
—	1	2	9	12	—	—	—	—	—	—	—	—	—	—	—
—	7	9	8	24	—	—	—	—	—	—	—	—	—	—	—

A-3. 1955, Mitkof (U.S.)

Date	Lat.(°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of shackles of varying mesh size[1]				Sockeye				Total
					2½	3¼	4½	5¼	2½	3¼	4½	5¼	
Aug. 12	52—02	164—43W	16.0	9.8	2	2	2	6	—	7	10	5	22
13	51—06	164—42W	13.5	10.1	2	2	2	6	—	9	17	15	41
14	50—00	165—25W	14.0	11.0	2	2	2	6	—	1	—	2	3
15	49—00	165—07W	16.0	11.6	2	2	2	6	—	1	—	—	1
16	48—00	164—55W	13.7	13.6	2	2	2	6	—	—	—	—	—
17	47—00	165—00W	15.2	15.2	2	2	2	6	—	—	—	—	—
18	46—00	164—57W	16.0	15.8	2	2	2	6	—	—	—	—	—
19	44—59	165—17W	14.5	16.8	2	2	2	6	—	—	—	—	—
20	45—00	167—35W	11.2	16.6	2	2	2	6	—	—	—	—	—
21	44—50	170—03W	12.5	16.6	2	2	2	6	—	—	—	—	—
22	45—58	169—56W	18.7	16.1	2	2	2	6	—	—	—	—	—
23	46—54	169—52W	16.5	15.5	2	2	2	6	—	—	—	—	—
24	47—56	170—07W	16.5	15.8	2	2	2	6	—	—	—	—	—
25	49—03	170—13W	15.5	12.0	2	2	2	6	—	—	—	—	—
26	50—00	170—08W	15.0	12.4	2	2	2	6	—	1	2	2	5
Sept. 3	50—00	175—00W	18.2	10.2	2	2	2	6	—	6	6	10	22
4	49—00	175—06W	15.0	10.8	2	2	2	6	—	2	2	—	4
7	48—00	175—00W	65.0	10.8	2	2	2	6	—	—	1	3	4
22	51—03	154—35W	21.5	10.1	2	2	2	6	—	5	—	5	10
23	50—05	154—42W	12.0	10.0	2	2	2	6	—	6	1	3	10
24	49—02	154—42W	14.2	10.9	2	2	2	6	—	—	—	—	—
25	47—57	155—00W	11.5	11.5	2	2	2	6	—	—	—	—	—
28	47—57	144—52W	23.0	12.9	2	2	2	6	—	—	—	—	—
Oct. 1	47—57	135—00W	22.0	13.7	2	2	2	6	—	—	—	—	—
3	47—56	129—52W	21.0	14.2	2	2	2	6	—	—	—	—	—
5	48—08	125—27W	7.0	10.1	2	2	2	6	—	—	—	—	—

[1] Mesh size in inches.

Chum					Pink					Coho					Chinook
2½	3¼	4½	5¼	Total	2½	3¼	4½	5¼	Total	2½	3¼	4½	5¼	Total	Total
—	4	8	19	31	—	—	—	—	—	—	—	—	—	—	—
—	8	5	3	16	—	—	—	—	—	—	—	—	—	—	—
—	4	9	3	16	—	—	—	—	—	—	—	—	—	—	—
—	1	—	1	2	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	2	1	3	—	—	—	—	—	—	—	—	—	—	1
—	—	3	4	7	—	—	—	—	—	—	—	—	—	—	—
—	—	1	—	1	—	—	—	—	—	—	—	—	—	—	—
—	—	2	10	12	—	—	—	—	—	—	—	—	—	—	1
—	1	1	—	2	—	—	—	—	—	—	—	—	1	1	—
—	1	—	1	2	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	2	2	—	—	—	—	—	—	—	—	1	1	1

A-4. 1955, Paragon (U.S.)

Date	Lat.(°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of shackles of varying mesh size[1]				Sockeye				
					2 1/2	3 1/4	4 1/2	5 1/4	2 1/2	3 1/4	4 1/2	5 1/4	Total
Aug. 13	50—00	175—00W	20.0	11.5	2	2	2	6	3	12	8	4	27
14	49—00	175—00W	16.5	12.7	2	2	2	6	—	1	1	—	2
15	48—00	175—00W	15.0	13.8	2	2	2	6	—	—	—	3	3
16	47—00	175—00W	16.2	15.4	2	2	2	6	—	—	—	—	—
17	46—00	175—00W	16.0	15.7	2	2	2	6	—	—	—	—	—
18	45—00	175—00W	14.5	16.2	2	2	2	6	—	—	—	—	—
19	45—00	177—30W	10.7	17.5	2	2	2	6	—	—	—	—	—
20	45—00	180—	10.0	17.6	2	2	2	6	—	—	—	—	—
21	45—00	177—30 E	11.7	19.1	2	2	2	6	—	—	—	—	—
22	45—00	175—00 E	8.7	18.1	2	2	2	6	—	—	—	—	—
23	46—03	175—25 E	14.2	16.4	2	2	2	6	—	—	—	—	—
24	47—00	175—00 E	13.2	14.6	2	2	2	6	—	—	—	—	—
25	48—00	175—00 E	16.2	14.2	2	2	2	6	—	—	—	—	—
26	49—00	175—00 E	16.5	12.7	2	2	2	6	—	—	—	—	—
27	50—00	175—00 E	11.7	10.8	2	2	2	6	—	1	—	—	1
28	50—00	177—30 E	12.7	10.7	2	2	2	6	—	6	5	—	11
Sept. 3	50—00	180	14.2	10.3	2	2	2	6	—	9	5	2	16
4	49—00	180	17.5	10.3	2	2	2	6	—	3	1	2	6
13	50—00	175—00 E	11.5	9.1	2	1	1	8	2	—	—	2	4
14	49—00	174—55 E	15.0	10.0	2	1	1	8	—	—	—	—	—
15	47—38	174—49 E	16.2	11.5	2	1	1	8	—	—	—	—	—
16	47—00	175—00 E	15.2	12.0	2	1	1	8	—	—	—	—	—
17	47—00	177—30 E	8.7	11.3	2	1	1	8	—	—	—	—	—
19	48—00	177—30W	14.7	10.1	2	1	1	8	—	—	—	—	—
20	50—00	175—00W	7.7	9.5	2	1	1	8	—	1	—	2	3
Oct. 3	51—00	145—00W	45.5	11.3	2	1	2	7	—	—	—	—	—

[1] Mesh size in inches.

Chum					Pink					Coho					Chinook
2½	3¼	4½	5¼	Total	2½	3¼	4½	5¼	Total	2½	3¼	4½	5¼	Total	Total
1	6	3	4	14	—	—	—	—	—	—	1	—	—	1	11
—	3	4	8	15	—	—	—	—	—	—	—	—	—	—	—
—	2	1	5	8	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	1	5	27	33	—	—	—	—	—	—	—	—	—	—	—
—	6	24	29	59	—	—	—	—	—	—	—	—	—	—	—
—	13	31	67	111	—	—	—	—	—	—	—	—	—	—	—
—	4	28	59	91	—	—	—	—	—	—	—	—	—	—	—
—	—	—	33	33	—	—	—	—	—	—	—	—	—	—	—
—	3	—	44	47	—	—	—	—	—	—	—	—	—	—	—
—	—	—	3	3	—	—	—	—	—	—	—	—	—	—	—
—	—	—	13	13	—	—	—	—	—	—	—	—	—	—	—
—	—	—	2	2	—	—	—	—	—	—	—	—	—	—	—
—	2	—	28	30	—	—	—	—	—	—	—	—	—	—	—
—	1	1	12	14	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

A-5. 1956, Challenger (Canada)

Date	Lat.(°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of shackles of varying mesh size[1]				Sockeye				
					2½	3¼	4½	5¼	2½	3¼	4½	5¼	Total
June 3	48—00	132—30W	8.0	10.8	1	1	1	3	—	—	—	—	—
4	48—00	135—00W	10.0	9.6	1	1	1	3	—	1	—	—	1
7	48—00	145—00W	10.5	7.6	1	1	1	3	1	—	1	1	3
July 8	54—00	137—30W	10.0	11.5	1	1	1	3	—	—	1	—	1
9	56—00	137—00W	9.0	12.0	3	3	3	9	—	—	3	6	9
10	58—00	137—00W	6.5	11.0	3	3	3	9	—	3	4	14	21
11	58—00	140—00W	7.0	11.0	3	3	3	9	—	—	5	11	16
12	58—00	145—00W	7.0	12.0	3	3	3	9	1	—	2	15	18
13*	58—00	150—00W	10.0	9.0	3	3	3	9	—	—	—	1	1
17	56—00	150—00W	9.5	12.1	3	3	3	9	4	1	4	22	31
18	54—00	150—00W	9.5	12.1	3	3	3	9	3	—	2	5	10
19	52—00	150—00W	6.0	9.3	3	3	3	9	1	—	1	3	5
20	50—00	150—00W	12.0	10.5	3	3	3	9	5	6	—	6	17
23*	50—00	140—00W	11.5	13.0	3	3	3	9	—	—	—	—	—
24	50—00	140—00W	12.0	12.5	3	3	3	9	—	—	—	—	—
25	50—00	137—30W	12.0	13.0	3	3	3	9	—	—	—	—	—
26	50—00	135—00W	12.0	13.5	3	3	3	9	—	—	—	—	—
Aug. 12	50—00	130—00W	7.0	15.0	4	4	4	12	—	—	—	—	—
15	52—00	132—00W	8.0	14.0	4	4	4	12	—	—	—	—	—
16*	54—00	135—00W	6.0	12.5	4	4	4	12	—	—	—	—	—
22	54—00	135—00W	12.0	14.0	4	4	4	12	—	—	—	—	—
23	54—00	137—30W	9.5	14.0	4	4	4	12	—	—	—	—	—
25	50—00	132—30W	8.0	16.0	4	4	4	12	—	—	—	—	—
26	48—00	130—00W	6.0	18.0	4	4	4	12	—	—	—	—	—
Sept. 6*	54—00	140—00W	8.0	13.9	4	4	4	12	—	—	—	—	—
7	54—00	140—00W	11.0	12.9	4	4	4	12	—	—	—	—	—
8	52—00	140—00W	8.5	13.0	4	4	4	12	—	—	—	—	—
9	52—00	137—30W	12.0	14.0	4	4	4	12	—	—	—	—	—
10	50—00	135—00W	8.0	14.3	4	4	4	12	—	—	—	—	—

* Day set. [1] Mesh size in inches.

A-6. 1956, Key West II (Canada)

Date	Lat.(°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of shackles of varying mesh size[1]				Sockeye				
					2½	3¼	4½	5¼	2½	3¼	4½	5¼	Total
May 23	54—00	135—00W	10.5	8.0	2	2	2	6	—	—	2	3	5
28	52—00	132—00W	8.0	9.4	3	3	3	9	8	2	—	—	10
29	50—00	130—00W	8.0	11.1	2	2	2	6	—	—	—	—	—
31	48—00	127—30W	6.5	12.5	3	3	3	9	—	1	—	—	1
June 18	46—00	135—00W	8.5	11.0	2	2	2	6	—	—	—	—	—
19	44—00	135—00W	9.0	12.1	2	2	2	6	—	—	—	—	—
20	42—00	135—00W	10.0	13.0	1	1	1	3	—	—	—	—	—
21	42—00	130—00W	5.0	13.0	1	1	1	3	—	—	—	—	—
22	42—00	127—35W	9.0	14.7	2	2	2	6	—	—	—	—	—
26	44—00	127—00W	9.0	14.8	2	2	2	6	—	—	—	—	—
27	46—00	127—00W	9.5	14.2	2	2	2	6	—	—	—	—	—
July 12	56—00	140—00W	8.0	10.2	3	3	3	9	—	—	—	5	5
13	56—00	145—00W	9.0	11.0	3	3	3	9	3	—	1	3	7
14	54—00	145—00W	9.0	11.4	3	3	3	9	2	1	1	2	6
15	52—00	145—00W	9.0	11.0	2	2	2	6	7	—	—	—	7
17	52—00	140—00W	9.5	12.0	2	2	2	6	—	—	3	8	11
18	54—00	140—00W	9.5	12.0	3	3	3	9	—	—	—	2	2
19	52—00	137—50W	10.0	12.2	2	2	2	6	—	—	—	—	—
20	52—00	135—00W	10.5	13.3	3	3	3	9	—	—	2	11	13

[1] Mesh size in inches.

Chum					Pink					Coho					Chinook				
$1/_2$	$3^1/_4$	$4^1/_2$	$5^1/_4$	Total	$2^1/_2$	$3^1/_4$	$4^1/_2$	$5^1/_4$	Total	$2^1/_2$	$3^1/_4$	$4^1/_2$	$5^1/_4$	Total	$2^1/_2$	$3^1/_4$	$4^1/_2$	$5^1/_4$	Total
—	—	—	—	—	—	13	—	—	13	—	1	1	1	3	—	—	—	—	—
—	1	—	—	1	—	—	—	—	—	—	2	—	—	2	—	—	—	—	—
—	—	—	1	1	—	—	1	—	1	—	—	—	3	3	—	—	—	2	2
1	1	—	1	3	—	—	—	—	—	1	—	2	2	5	—	—	—	—	—
1	7	12	14	34	—	1	1	2	4	—	1	5	12	18	—	—	—	1	1
—	—	4	27	31	—	1	9	10	20	—	1	4	5	10	—	—	—	—	—
—	2	1	9	12	—	2	2	1	5	—	—	4	6	10	—	—	—	—	—
—	—	1	—	1	—	1	10	13	24	2	1	2	16	21	—	—	—	—	—
—	—	—	19	19	—	—	—	—	—	—	—	—	1	1	—	—	—	—	—
3	16	23	—	42	—	—	11	19	30	—	—	2	6	8	—	—	—	—	—
2	—	8	5	15	—	—	11	8	19	1	—	1	5	7	—	—	1	—	1
—	—	5	2	7	—	—	3	4	7	—	—	—	2	2	—	—	—	—	—
1	6	—	1	8	—	—	—	1	1	—	—	—		—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	1	—	—	1	—	1	1	1	3	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	1	1	—	—	—	—	—	—	—	—	—	—
—	1	3	51	55	—	—	10	46	56	1	—	2	14	17	—	—	—	—	—
—	—	—	—	—	—	—	—	1	1	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	1	1	—	—	—	—	—	—	—	—	—	—
—	—	2	4	6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Chum					Pink					Coho					Chinook				
$2^1/_2$	$3^1/_4$	$4^1/_2$	$5^1/_4$	Total	$2^1/_2$	$3^1/_4$	$4^1/_2$	$5^1/_4$	Total	$2^1/_2$	$3^1/_4$	$4^1/_2$	$5^1/_4$	Total	$2^1/_2$	$3^1/_4$	$4^1/_2$	$5^1/_4$	Total
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
8	2	—	—	10	—	1	2	1	4	—	—	—	1	1	—	—	—	—	—
—	—	—	—	—	—	3	—	1	4	—	—	—	1	1	—	—	—	—	—
—	—	—	—	—	—	—	—	1	1	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	1	1	2	—	—	—	1	1	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	2	3	1	6	1	—	2	4	7	—	—	—	—	—
—	2	2	4	8	—	1	8	9	18	4	—	1	6	11	—	—	—	—	—
—	28	7	1	36	—	1	5	—	6	1	—	1	3	5	—	—	—	—	—
2	3	4	2	11	—	2	1	—	3	—	—	3	—	3	—	—	1	—	1
1	6	2	—	9	—	1	2	—	3	—	—	—			—	—			
6	14	—	1	21	—	3	7	—	10	—									
—	1	—	—	1	—	—	2	—	2	—	—	—	—	—					
1	2	3	11	17	—	—	4	1	5	—	—	—	3	3	—	—	—	—	—

A-7. 1956. Eiko-maru (Japan)

Date		Lat. (°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of tans[1] of varying mesh size[2]					Sockeye					
						5.4	4.8	4.2	3.6	3.0	5.4	4.8	4.2	3.6	3.0	Total
May	24	49—00	174—50 E	12	4.5	6	216	9	6	5	1	119	—	—	—	120
	26	49—00	177—00 E	9	4.3	—	80	—	—	—	—	14	—	—	—	14
	27	48—50	178—50 E	14	5.0	6	144	9	6	5	3	18	3	7	—	31
	28	48—50	179—05W	10	5.0	6	66	8	6	5	—	19	—	—	—	19
	30	47—30	178—50 E	11	5.2	6	213	6	6	5	1	25	1	1	—	28
	31	47—30	177—05 E	10	5.0	6	65	4	6	5	—	6	2	1	—	9
June	1	48—13	175—41 E	13	5.0	6	211	4	4	5	—	189	4	—	—	193
	2	49—38	176—02 E	9	4.6	6	64	4	4	5	1	11	1	—	—	13
	3	50—35	174—45 E	5	—	6	64	4	4	5	—	—	3	—	—	3
	5	52—07	172—41 E	13	4.7	6	260	4	4	5	7	166	2	5	—	180
	6	53—13	172—45 E	9	4.4	6	259	4	4	5	5	51	—	—	—	56
	7	53—33	174—45 E	12	4.5	6	259	4	4	5	7	384	4	2	2	399
	8	53—41	175—00 E	12	4.1	6	259	4	4	5	—	112	3	—	—	115
	9	54—53	175—00 E	8	4.0	6	64	4	4	5	2	16	—	—	—	18
	10	56—22	175—12 E	11	4.1	6	259	4	4	5	—	103	—	—	—	103
	13	56—45	179—40 E	12	4.1	6	259	4	4	5	1	195	1	—	1	198
	14	55—22	179—30 E	8	4.2	6	64	4	4	5	—	26	—	4	1	31
	15	53—39	179—58W	9	4.6	6	116	4	4	5	4	154	4	—	1	163
	16	53—53	177—23W	11	5.1	6	259	4	4	5	4	192	2	1	—	199
	17	53—29	175—09W	8	5.6	6	64	4	4	5	6	205	6	—	3	220
	18	54—50	175—00W	10	6.1	6	259	4	4	5	10	468	3	4	—	485
	19	56—20	175—08W	11	5.0	6	259	4	4	4	5	494	5	1	—	505
	20	57—45	175—11W	10	5.3	6	259	4	4	4	29	637	6	3	3	678
July	6	53—50	179—45W	12	6.9	6	262	4	4	4	5	90	1	2	—	98
	7	53—36	178—30 E	11	7.0	6	262	4	4	4	1	29	4	2	5	41
	8	53—42	176—11 E	7	7.0	—	101	—	—	—	—	15	—	—	—	15
	10	50—58	172—33 E	12	7.3	6	261	4	4	4	—	66	6	13	11	96
	13	47—52	173—00 E	13	8.4	6	261	4	4	4	—	—	—	—	—	—
	17	46—44	168—16 E	11	9.0	6	211	4	4	4	—	—	—	—	—	—
	18	46—50	168—27 E	13	9.4	5	205	4	4	4	—	—	—	—	—	—
	19	46—52	168—23 E	10	9.5	5	203	4	4	4	—	—	—	—	—	—
	20	46—50	168—05 E	11	10.2	5	183	4	4	4	—	—	—	—	—	—
	21	46—57	167—54 E	?	10.0	5	183	4	4	4	—	—	—	—	—	—
	25	53—04	168—55 E	7	8.9	4	135	4	4	2	7	239	23	10	3	282
	26	54—48	169—35 E	13	9.3	4	136	4	4	2	1	88	5	—	4	98
	27	56—00	169—47 E	11	8.6	4	136	4	4	2	1	103	2	—	—	106
	28	56—06	168—02 E	13	8.8	4	136	4	4	2	2	179	2	—	2	185
	29	56—14	166—44 E	12	9.4	4	136	4	4	2	5	337	9	9	9	369
	30	56—12	164—55 E	11	12.0	4	136	4	4	2	1	147	7	7	7	169
	31	55—25	164—30 E	11	9.8	4	136	4	4	2	2	182	6	2	6	198
Aug.	1	56—02	165—00 E	12	10.5	4	136	4	4	2	—	120	1	2	4	127
	2	56—10	167—57 E	12	9.7	4	136	4	4	2	2	62	2	1	5	72
	3	55—35	168—07 E	11	9.4	4	136	4	4	2	—	55	1	—	1	57
	4	54—10	168—42 E	11	9.3	4	136	4	4	2	—	36	2	1	1	40
	5	54—05	168—47 E	9	9.3	4	136	4	4	2	—	23	—	—	—	23
	6	53—36	167—51 E	11	9.7	4	136	4	4	2	2	122	3	12	1	140
	7	53—42	167—40 E	12	10.2	4	136	4	4	2	2	290	2	13	1	308
	8	53—55	167—20 E	10	10.0	4	136	4	4	2	1	91	3	4	1	100
	9	53—26	166—48 E	7	9.8	4	136	4	4	2	—	56	3	1	—	60
	10	52—34	165—18 E	12	10.4	4	136	4	4	2	—	113	5	2	—	120
	11	52—20	165—20 E	10	10.6	4	136	4	4	2	1	85	3	—	—	89

[1] Length of one tan is 180 feet. [2] Mesh size in sun (see conversion factors, p. 129).

Chum						Pink						Coho						Chinook					
5.4	4.8	4.2	3.6	3.0	Total	5.4	4.8	4.2	3.6	3.0	Total	5.4	4.8	4.2	3.6	3.0	Total	5.4	4.8	4.2	3.6	3.0	Total
12	655	3	2	1	673	—	—	—	—	—	—	—	—	—	—	—	—	1	3	—	—	—	4
—	17	—	—		17	—	—	—	—	—	—	—	—	—	—	—	—	—	—		—	—	—
1	51	2	—	—	54	—	5	1	—	—	6	—	—	—	—	—	—	—	—	—	—	—	
—	145	8	1	1	155	—	10	—	—	—	10	—	—	—	—	—	—	—	—	—	—	—	—
—	30		1	—	31	—	70	—	2	—	72	—	—	—			—	—			—	—	—
—	35	2	3	—	40	—	13	—	1	—	14	—	—	—		—	—	—	—	—	—	—	—
—	151	2	—		153	—	65	2	1	—	68	—	—	—			—	—	—	—	—	—	—
4	24	2	—	—	30	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	18	—	—	18	—	—	—		—	—	—	—	—	—	—	—	—	—	—	—	—	—
1	474	4	3	—	482	—	3	—	—	—	3	—	—	—	—	—	—	—	—	—	—	—	—
35	748	4	—		787	—	—		—	—	—	—	—	—	—	—	—	—	2	—	—	—	2
22	2124	10	2		2158	—	64	1	—	—	65	—	—	—	—	—	—	—	—	—	—	—	—
—	1303	21	3	—	1327	—	116	10	—	—	126	—	—	—	—	—	—	—	—	—	—	—	—
4	53	—		—	57	—	2	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—
9	422	1	—		432	—	11	—	—	—	11	—	—	—	—	—	—	—	—	—	—	—	—
—	642	2	4	—	648	—	25	—	—		25	—	—	—	—	—	—	—	—	—	—	—	—
5	291	9	3	—	308	—	6	1	1	1	9	—	—	—	—	—	—	—	—	—	—	—	—
2	49	2	1		54	—	8	—	1	—	9	—	—	—		—		—	—	—	—	—	—
5	145	2	1	—	153	—	10	—	—	—	10		—	—	—	—	—	—	—	—	—	—	—
1	31	1		—	33	—	1	—	—	—	1	—	—	—	—	—	—	—	1	—	—	—	1
1	85	—	—	—	86		9	—	1	—	10	—	—	—	—	—	—	—	26	—	—	—	26
4	179	—	—	—	183	—	6	—	—	—	6	—	—	—	—	—	—	—	1	—	—	—	1
11	671	2	—		184	—	9	—	—	—	9	—	—	—	—	—	—	—	3	—	—	—	3
—	101	3	6	6	116	—	2	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—
1	42	4	3	35	85	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	2
—	14	—	—	—	14	—	—	—	—	—	—	—	1	—	—	—	1	—	—	—	—	—	—
1	13	1	1	28	44	—	1	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
—	5	—	—	1	6	—	—	—	—	—	—	1	19	1	—	—	21	—	1	—	—	—	1
1	18	—	1	—	20	5	146	5	4	—	160	7	155	1	—	—	163	—	4	—	—	—	4
1	41	—	2	1	45	1	696	4	11	—	712	11	711	2	2	1	727	—	—	—	—	—	—
—	16	3	2	—	21	4	277	3	3	—	287	5	163	2	—	—	170	—	1	—	—	—	1
2	52	6	4	1	65	4	217	3	1	—	225	4	50	—	2	1	57	1	6	—	—	1	8
2	16	—	2	2	22	1	172	1	1	—	175	3	35	—	1	—	39		—		—	—	—
1	36	2	—	2	41		2	—	—	—	2	2	5	1	—	—	8	1	4	—	—	—	5
3	67	1	—	1	72	—	4	—	—	—	4	—	—	—	—	—		—	—			—	
7	245	3	2	2	259		—	—	—	—	—	—	2	—	—	—	2	—			—	—	—
5	1194	19	—	7	1225	—	3	—	—	—	3	—	2	—	—	—	2	—	—	—		—	
10	276	9	7	6	308	—	3	—	—	—	3	—	2	—	—	—	2	—	—		—		—
9	254	3	6	13	285	—	3	—	—	—	3	—	2	—	—	—	2	—			—	—	
6	166	9	3	1	185	—	2	—	—	—	2	—	1	—	—	—	1			—	—	—	
3	90	2	—	9	105	—	2	—	—	—	2	—		—		—	—		—	—		—	—
4	157	7	4	3	175	—	50	4	4	2	60		—		—		—	—			—	—	
6	97	2	—	—	105		52	3	2	1	59		—		—			—			—	—	
10	527	2	3	1	543	—	38	5	3	—	46	—					—	—	—			—	—
5	124	—	—		129	—	36	4	—	—	40	—	2	—	—	—	2	—	1	—	—	—	1
3	71	4	2		80	—	59	3	2	1	65	—	7	—	—	—	7	—			—	—	—
—	121	4	2	1	128	—	50	3	2	—	55	1	—	4	—	—	5	—	1	—	—	—	1
4	134	1	—	—	139	—	18	2	1	—	21	2	1	—	—	—	3	—	—	—		—	—
6	34	—	—	—	40	—	22	5	—	—	27	2	1	—	—	—	3	—	—	—	—	—	—
5	162	1	2	—	170	—	47	4	2	—	53	7	55	1	—	—	63	—			—	—	—
3	57	1			61	—	37	2	—	—	39	4	20	—	2	—	26						

A-8. 1956, Etsuzan-maru (Japan)

Date		Lat. (°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of tans[1] of varying mesh size[2]					Sockeye					
						5.4	4.8	4.2	3.6	3.0	5.4	4.8	4.2	3.6	3.0	Total
May	19	39—14	171—19W	11	12.6	5	155	10	6	4	—	—	—	—	—	—
	25	43—10	169—50W	13	9.8	5	156	10	6	4	—	—	—	—	—	—
	28	42—29	175—05W	8	10.8	—	60	—	—	—	—	—	—	—	—	—
	30	42—26	177—55W	12	10.4	5	165	10	6	4	—	—	—	—	—	—
June	1	45—54	179—36W	14	6.7	5	305	10	6	4	—	6	—	—	—	6
	5	46—32	174—45W	11	5.4	5	95	10	6	4	5	5	—	9	2	21
	8	46—00	165—05W	13	7.8	5	97	10	6	2	1	3	—	—	5	9
	10	49—19	165—03W	13	5.8	5	293	10	6	4	1	35	9	—	2	47
	15	48—56	179—43W	14	5.5	5	293	10	6	4	—	14	—	6	3	23
	17	50—21	175—34 E	11	5.0	5	155	10	6	4	5	130	15	1	5	156
	18	51—15	173—00 E	13	5.1	5	292	10	6	4	—	151	6	—	2	159
	19	52—01	172—34 E	11	5.2	—	180	—	—	—	—	41	—	—	—	41
	20	51—52	171—21 E	10	4.9	—	180	—	—	—	—	6	—	—	—	6
	22	53—13	179—09 E	12	5.4	5	169	10	6	4	—	96	—	—	—	96
	23	53—47	178—53W	12	5.3	5	210	10	6	4	27	390	—	—	—	417
	30	52—08	176—35W	3	6.4	—	60	—	—	—	—	2	—	—	—	2
July	6	55—05	179—39W	13	7.2	3	215	10	6	4	9	68	5	1	—	83
	7	54—37	178—55 E	11	6.4	5	212	10	6	4	5	27	14	2	5	53
	9	55—44	171—58 E	11	6.8	5	212	10	6	4	17	42	—	3	—	62
	15	48—15	170—50 E	12	8.7	5	267	10	6	4	—	6	—	—	—	6
	16	48—48	170—35 E	14	8.8	5	221	10	6	4	—	4	—	—	—	4
	17	47—36	169—27 E	10	8.9	—	180	—	—	—	—	—	—	—	—	—
	18	46—02	169—45 E	11	9.9	—	190	—	—	—	—	—	—	—	—	—
	19	46—07	168—39 E	11	11.1	5	281	10	6	4	—	—	—	—	—	—
	20	46—48	167—35 E	11	10.2	5	218	10	6	4	—	—	—	—	—	—
	21	47—05	168—39 E	11	9.8	5	215	10	6	4	—	—	—	—	—	—
	26	56—58	169—10 E	10	8.2	2	138	5	3	2	3	113	8	15	7	146
	27	57—59	168—33 E	11	8.3	2	137	5	3	2	—	216	4	5	1	226
	28	57—49	169—59 E	11	8.8	2	137	5	3	2	5	304	7	5	5	326
	29	56—08	169—41 E	11	8.7	2	137	5	3	2	—	97	7	7	6	117
	30	58—45	167—40 E	10	10.4	2	136	5	3	2	10	431	16	10	7	474
	31	57—58	166—16 E	11	9.4	2	138	5	3	2	3	131	2	2	4	142
Aug.	1	56—50	166—20 E	11	9.7	2	138	5	3	2	5	230	7	5	5	252
	2	56—11	167—47 E	11	9.0	2	138	5	3	2	5	81	6	5	4	101
	3	57—11	168—10 E	10	9.9	2	138	5	3	2	4	137	7	5	4	157
	5	54—03	169—10 E	11	9.9	2	138	5	3	2	5	101	5	5	1	117
	6	53—57	169—07 E	11	9.9	2	134	5	3	2	5	358	10	5	4	382
	7	53—46	169—52 E	12	10.0	2	138	5	3	2	6	552	15	11	6	590
	8	53—43	169—53 E	13	10.7	2	138	5	3	2	6	356	15	5	4	386
	9	53—45	169—34 E	?	10.6	2	138	5	3	2	5	300	12	5	—	322
	10	53—09	170—19 E	12	10.3	2	138	5	3	2	10	480	24	5	1	520

[1] Length of one tan is 180 feet.

[2] Mesh size in sun (see conversion factors, p. 129).

[3] Catch of pink salmon by gillnets of varying mesh size was not recorded.

Chum						Pink						Coho						Chinook					
5.4	4.8	4.2	3.6	3.0	Total	5.4	4.8	4.2	3.6	3.0	Total	5.4	4.8	4.2	3.6	3.0	Total	5.4	4.8	4.2	3.6	3.0	Total
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	4	5	—	1	10	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	10[3]	—	—	—	—	—	—	—	—	—	—	—	—
—	1	—	—	—	1	—	—	—	—	—	10[3]	—	—	—	—	—	—	—	1	—	—	—	1
8	108	10	15	3	144	—	—	—	—	—	26[3]	—	—	—	—	—	—	—	20	—	—	—	20
6	6	4	1	—	17	—	—	—	—	—	45[3]	—	—	—	—	—	—	—	8	—	—	—	8
8	24	—	1	—	33	—	—	—	—	—	35[3]	—	10	—	—	—	10	—	—	—	—	—	—
4	191	15	—	2	212	—	—	—	—	—	65[3]	—	—	—	—	—	—	—	—	—	—	—	—
—	14	—	13	6	33	—	—	—	—	—	15[3]	—	—	—	—	—	—	—	—	—	—	—	—
9	172	22	1	33	237	—	22	3	—	25	50	—	—	—	—	—	—	—	—	2	—	—	2
3	301	2	—	2	308	—	31	—	—	—	31	—	—	—	—	—	—	—	—	—	—	—	—
—	31	—	—	—	31	—	—	—	—	—	6[3]	—	—	—	—	—	—	—	—	—	—	—	—
—	38	—	—	—	38	—	—	—	—	—	6[3]	—	—	—	—	—	—	—	—	—	—	—	—
—	42	—	—	—	42	—	—	—	—	—	4[3]	—	—	—	—	—	—	—	—	—	—	—	—
45	242	—	—	—	287	—	—	—	—	—	8[3]	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
7	42	9	3	—	61	—	1	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
20	100	71	8	27	226	—	4	—	—	—	4	—	—	—	—	—	—	—	1	—	—	—	1
32	104	16	17	14	183	—	—	—	—	—	3[3]	—	1	—	—	—	1	—	1	—	—	—	1
—	102	13	15	—	130	—	15	—	—	—	15	—	152	23	27	—	202	—	2	—	—	—	2
—	14	8	7	2	31	—	—	12	—	—	12	30	56	12	—	—	98	—	2	—	—	—	2
—	11	—	—	—	11	—	19	—	—	—	19	—	34	—	—	—	34	—	2	—	—	—	2
—	20	—	—	—	20	—	54	—	—	—	54	—	171	—	—	—	171	—	4	—	—	—	4
—	20	—	—	—	20	—	15	—	—	—	15	—	82	—	—	—	82	—	—	—	—	—	—
1	111	4	3	4	123	—	109	—	—	—	109	—	194	—	—	—	194	—	—	—	—	—	—
—	49	—	4	4	57	—	214	—	—	—	214	—	294	—	—	—	294	—	3	—	—	—	3
—	821	20	25	5	871	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2	618	4	5	3	632	—	1	—	—	—	1	—	—	—	—	—	—	—	1	—	—	—	1
7	750	15	15	9	796	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	121	10	12	7	150	—	1	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
5	203	7	15	7	237	—	—	—	—	—	—	—	1	—	—	—	1	—	—	—	—	—	—
—	97	1	2	2	102	—	—	—	—	—	—	—	5	—	—	—	5	—	—	—	—	—	—
4	186	8	5	4	207	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
5	135	5	5	4	154	—	—	—	—	—	—	—	5	—	—	—	5	—	—	—	—	—	—
5	66	5	6	4	86	—	1	—	—	—	1	—	2	—	—	—	2	—	3	—	—	—	3
5	442	7	6	7	467	—	1	—	—	—	1	—	13	—	—	—	13	—	1	—	—	—	1
4	173	5	5	6	193	—	1	—	—	—	1	—	51	—	—	—	51	—	—	—	—	—	—
4	365	7	5	—	381	—	2	—	—	—	2	—	42	—	—	—	42	—	3	—	—	—	3
5	279	11	3	2	300	—	2	—	—	—	2	—	14	—	—	—	14	—	7	—	—	—	7
5	92	6	3	—	106	—	—	—	—	—	—	—	28	—	—	—	28	—	1	—	—	—	1
5	217	—	—	—	222	—	4	—	—	—	4	—	19	—	—	—	19	—	2	—	—	—	2

A-9. 1956, TAKUYO-MARU (Japan)

Date		Lat.(°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of tans[1] of varying mesh size[2]					Sockeye					
						5.4	4.8	4.2	3.6	3.0	5.4	4.8	4.2	3.6	3.0	Total
May	14	39—55	164—25 E	12	15.2	5	65	8	6	5	—	—	—	—	—	—
	18	39—45	173—30 E	12	13.9	5	37	8	6	5	—	—	—	—	—	—
	20	43—00	175—11 E	11	11.0	5	37	8	6	5	—	—	—	—	—	—
	24	42—39	165—37 E	12	7.9	6	65	8	6	5	—	—	—	—	—	—
	27	45—19	164—15 E	12	5.0	6	25	8	6	5	—	61	19	—	1	81
	29	45—20	170—02 E	11	6.9	6	25	8	6	5	—	8	9	25	13	55
	31	45—30	174—52 E	12	5.2	6	25	8	6	5	3	16	20	47	10	96
June	1	46—50	175—27 E	?	6.0	6	25	8	6	5	—	22	7	11	12	52
	6	48—59	174—56 E	11	5.2	6	65	8	6	5	—	11	8	6	5	30
	7	50—25	173—31 E	12	5.2	6	67	8	6	5	4	17	—	—	—	21
	15	48—33	172—16 E	13	5.2	6	67	8	6	5	3	92	41	51	8	195
	17	48—52	177—11 E	12	5.3	6	67	8	6	5	1	41	9	35	4	90
	18	49—34	177—29 E	12	5.6	6	67	8	6	5	1	4	3	5	2	15
	19	49—50	179—27 E	12	5.5	6	67	8	6	5	—	16	5	7	1	29
	20	50—15	178—24W	14	5.7	6	35	8	6	5	1	23	8	8	7	47
	22	52—29	177—50W	11	5.4	4	33	8	6	5	—	27	11	5	—	43
	23	52—13	176—31W	9	5.5	4	33	8	6	5	2	10	3	—	1	16
July	7	54—55	179—42 E	11	6.5	4	32	6	4	4	1	5	3	—	1	10
	14	46—10	168—26 E	12	8.4	5	61	6	4	4	—	—	—	—	—	—
	15	46—06	168—08 E	13	8.4	5	139	6	4	4	—	—	—	—	—	—
	16	46—06	168—00 E	12	9.2	5	140	6	4	5	—	—	—	—	—	—
	17	46—18	168—02 E	12	9.6	5	140	6	4	5	—	—	—	—	—	—
	18	46—25	168—07 E	12	9.6	5	140	6	4	5	—	—	—	—	—	—
	19	46—36	167—58 E	13	10.2	5	140	6	4	5	—	—	—	—	—	—
	21	46—43	167—43 E	12	10.6	5	137	6	4	5	—	—	—	—	—	—
	25	53—00	167—41 E	12	8.7	4	136	6	2	2	—	195	5	—	1	201
	26	53—51	169—46 E	12	9.0	4	135	6	2	2	2	552	28	5	3	590
	27	53—32	167—51 E	12	8.0	4	66	6	2	2	4	194	34	13	7	252
	29	53—52	164—20 E	12	8.8	4	66	6	2	2	2	149	36	11	—	198
	30	53—00	162—45 E	12	9.2	4	135	6	2	2	5	251	13	6	2	277
	31	52—57	164—10 E	14	9.8	4	136	6	2	2	2	467	37	22	3	531
Aug.	1	53—07	166—08 E	13	9.1	4	136	6	2	2	2	564	29	3	—	598
	2	53—05	167—25 E	12	9.4	4	136	6	2	2	4	545	31	8	—	588
	3	53—06	167—17 E	13	9.4	4	136	6	2	2	—	210	19	7	1	237
	5	53—15	166—47 E	13	9.6	4	136	6	2	2	3	256	17	8	—	284
	6	53—20	166—13 E	12	10.1	4	136	6	2	2	2	411	38	8	2	461
	7	53—16	165—40 E	13	10.9	4	136	6	2	2	4	280	28	4	1	317
	8	53—24	165—27 E	12	10.6	4	136	6	2	2	3	171	18	4	1	197
	10	51—24	163—20 E	12	11.4	4	136	6	2	2	—	2	—	—	—	2
	11	50—33	162—30 E	13	12.0	4	136	6	2	2	1	15	2	3	—	21
	12	49—14	160—24 E	11	12.2	4	66	6	2	2	—	—	—	—	—	—

[1] Length of one tan is 180 feet.

[2] Mesh size in sun (see conversion factors, p. 129).

Chum						Pink						Coho						Chinook					
5.4	4.8	4.2	3.6	3.0	Total	5.4	4.8	4.2	3.6	3.0	Total	5.4	4.8	4.2	3.6	3.0	Total	5.4	4.8	4.2	3.6	3.0	Total
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	6	—	3	—	9	—	9	1	13	5	28	—	—	—	—	—	—	—	—	—	—	—	—
1	5	4	—	1	11	1	1	3	6	3	14	—	—	—	—	—	—	—	—	—	—	—	—
1	68	11	—	3	83	2	20	5	—	3	30	—	—	—	—	—	—	—	2	—	—	—	2
—	2	—	2	1	5	—	30	9	13	2	54	1	4	—	—	—	5	—	—	—	—	—	—
—	—	2	12	5	19	—	1	3	6	2	12	—	8	1	1	—	10	—	—	—	—	—	—
—	14	5	4	1	24	—	25	8	8	1	42	—	—	—	—	—	—	—	—	—	1	—	1
1	47	4	1	—	53	—	43	10	1	1	55	—	—	4	1	1	6	—	—	—	—	—	—
9	185	21	4	—	219	—	12	6	3	—	21	—	—	—	—	—	—	—	1	—	—	—	1
1	47	22	31	11	112	—	31	10	4	1	46	—	—	—	—	—	—	—	—	—	—	—	—
1	19	7	21	12	60	—	10	4	2	—	16	—	4	1	—	—	5	—	—	—	—	—	—
3	58	5	11	4	81	—	5	—	—	—	5	—	1	—	—	—	1	—	—	—	—	—	—
1	8	1	1	—	11	—	1	—	—	—	1	—	1	—	—	—	1	—	2	—	—	—	2
2	9	7	32	48	98	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	1	—	—	—	1	—	1	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
—	13	—	—	—	13	—	1	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
2	35	22	27	49	135	—	2	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—
—	49	6	7	1	63	—	127	18	11	—	156	3	42	5	1	—	51	—	1	—	—	—	1
1	141	11	3	—	156	—	302	12	6	—	320	—	81	—	2	—	83	—	—	—	—	—	—
—	24	5	6	—	35	—	64	4	3	—	71	—	36	—	1	—	37	—	—	—	—	—	—
1	71	—	2	—	74	—	69	3	2	—	74	—	40	—	1	—	41	—	—	—	—	—	—
2	63	4	2	—	71	1	222	4	—	—	227	3	158	4	1	—	166	—	14	—	—	—	14
2	85	4	2	—	93	3	331	9	6	—	349	8	429	9	7	1	454	—	5	1	—	—	6
2	112	9	3	—	126	1	62	2	—	1	66	2	71	—	—	—	73	—	12	—	—	—	12
6	62	—	—	—	64	—	8	1	—	—	9	—	37	—	—	—	37	—	2	—	—	—	2
4	208	11	7	1	231	—	2	—	—	—	2	—	3	—	—	—	3	—	2	—	—	—	2
—	33	3	4	2	42	—	2	—	—	—	2	1	5	—	—	—	6	—	1	—	—	—	1
—	95	9	1	—	105	1	5	2	—	—	8	1	22	1	—	—	24	—	—	—	—	—	—
4	78	—	—	1	83	—	11	2	—	—	13	2	68	4	—	—	74	2	—	—	—	—	2
2	57	2	2	—	63	1	12	—	—	—	13	2	66	2	—	—	70	—	1	—	—	—	1
—	47	2	2	2	53	—	2	—	—	—	2	—	23	1	—	—	24	—	2	—	—	—	2
2	138	7	3	9	159	—	4	—	—	—	4	3	19	—	—	—	22	—	1	—	—	—	1
3	120	7	1	1	132	—	10	—	—	—	10	1	36	—	—	—	37	—	2	—	—	—	2
2	75	2	—	—	79	—	8	1	—	—	9	4	18	—	—	—	22	—	—	—	—	—	—
3	73	2	—	—	78	1	3	—	—	—	4	—	19	2	—	1	22	—	1	—	—	—	1
3	58	3	—	—	64	—	1	—	—	—	1	2	24	1	—	—	29	—	—	—	—	—	—
—	92	6	—	—	98	—	1	—	—	—	1	1	55	1	—	—	57	—	—	—	—	—	—
3	211	12	3	—	229	—	13	—	—	—	13	—	75	—	—	—	75	—	2	—	—	—	2
2	39	—	1	3	45	1	48	—	—	—	49	1	135	—	—	—	136	—	2	—	—	—	2
—	13	1	1	—	15	—	58	4	—	—	62	—	65	2	—	—	67	—	1	—	—	—	1

A-10. 1956, Celtic (U.S.)

Date		Lat.(°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of shackles of varying mesh size[1]				Sockeye				
						2½	3¼	4½	5¼	2½	3¼	4½	5¼	Total
July	13	53—00	145—00W	13.0	10.0	3	3	6	6	2	6	2	3	13
	14	52—00	144—58W	11.2	10.6	3	3	6	6	—	5	3	1	9
	16	51—00	145—00W	33.0	10.6	3	3	6	6	—	—	1	5	6
	17	50—00	145—00W	12.5	11.0	3	3	6	6	4	1	1	2	8
	18	49—00	145—00W	12.5	11.2	3	3	6	6	—	—	1		1
	19	48—00	145—00W	12.5	12.3	3	3	6	6	—	—	—		
	21	48—00	150—00W	20.5	11.2	3	3	6	6	—	—	1		1
	22	49—00	150—00W	12.7	10.4	3	3	6	6	—	4	2	1	7
	23	50—00	150—00W	12.0	10.3	3	3	6	6	1	4	—		5
	24	51—00	150—00W	13.7	10.7	3	3	6	6	1	17	4		22
	25	52—00	150—00W	13.5	10.2	3	3	6	6	—	4	5		9
	26	53—00	150—00W	12.7	10.6	3	3	6	6	2	1	8	6	17
	31	59—00	145—00W	11.0	14.1	3	3	6	6	—	—	4	1	5
Aug.	1	58—10	144—55W	12.2	13.1	3	3	6	6	—	1	1	4	6
	2	57—00	145—00W	12.2	12.2	3	3	6	6	—	1	2	1	4
	3	56—00	144—50W	13.0	12.2	3	3	6	6	—	—	—		
	4	54—57	145—00W	14.0	11.7	3	3	6	6	—	2	—	1	3
	5	54—00	145—00W	15.0	11.1	3	3	6	6	—	—	13	2	15
	7	54—00	150—00W	20.5	11.4	3	3	6	6	1	7	19	4	31
	8	55—00	150—00W	12.5	12.2	3	3	6	6	—	1	5	7	13
	9	56—00	150—04W	14.5	12.8	3	3	6	6	—	—	5	5	10
	10	57—00	150—00W	14.5	13.1	3	3	6	6	—	1	3	3	7
	11	58—00	150—00W	15.2	10.1	3	3	6	6	—	—	2	7	9
	17	55—00	155—00W	11.2	12.2	3	3	6	6	1	—	1		2
	18	54—00	155—00W	14.0	12.8	3	3	6	6	—	8	43	7	58
	19	53—00	155—00W	13.7	12.8	3	3	6	6	6	17	70	17	110
	20	52—50	155—00W	17.7	12.2	3	3	6	6	2	2	27	14	45
	21	52—00	155—00W	14.2	11.7	3	3	6	6	1	1	23	9	34
	22	51—00	155—00W	14.0	11.7	3	3	6	6	—	16	16	4	36
	23	50—00	155—00W	14.0	11.1	3	3	6	6	—	10	7	1	18
	26	49—00	155—00W	62.0	11.1	3	3	6	6	—	—	1		1
	28	48—00	155—00W	14.7	11.7	3	3	6	6	—	—	—		
	30	48—00	150—00W	20.2	12.8	2	3	6	6	—	—	—		
	31	49—00	150—00W	11.0	11.7	2	3	6	6	—	—	—		
Sept.	1	50—00	150—00W	13.5	11.6	2	3	6	6	—	—	—		
	2	51—00	150—00W	12.0	11.1	2	3	6	6	—	2	1		3
	3	52—00	150—00W	14.0	11.3	2	3	6	6	—	8	6	2	16
	4	53—00	150—00W	13.2	11.3	2	3	6	6	—	8	27	9	44
	12	53—00	145—00W	15.2	12.5	3	3	6	6	—	2	—		2
	13	52—00	145—00W	12.7	13.1	3	3	6	6	—	—	—		
	14	51—00	145—00W	13.7	13.6	3	3	6	6	—	—	—		
	15	50—00	145—00W	13.2	14.0	3	3	6	6	—	—	—		
	17	52—00	140—00W	16.7	14.3	3	3	6	6	—	—	—		
	18	51—00	140—00W	12.2	14.3	3	3	6	6	—	—	—		
	19	50—00	140—00W	—	14.2	3	3	5	6	—	—	—		

[1] Mesh size in inches.

Chum					Pink					Coho					Chinook
2½	3¼	4½	5¼	Total	2½	3¼	4½	5¼	Total	2½	3¼	4½	5¼	Total	Total
—	15	86	—	101	—	2	6	4	12	—	—	2	—	2	—
1	11	28	2	42	—	—	2	1	3	—	—	—	—	—	1
—	4	27	2	33	—	—	3	—	3	—	—	—	—	—	—
6	56	28	9	99	—	—	2	—	2	—	1	3	10	14	1
1	6	18	1	26	—	—	—	—	—	—	—	—	—	—	—
1	1	2	—	4	—	—	—	—	—	—	—	—	—	—	—
1	14	17	2	34	—	—	—	—	—	—	—	—	4	4	—
—	39	24	5	68	—	—	—	—	—	—	—	—	3	3	1
1	42	21	16	80	—	—	—	1	1	—	—	—	3	3	—
—	32	23	2	57	—	—	2	1	3	—	—	—	3	3	1
—	5	25	2	32	—	—	3	—	3	—	—	3	2	5	—
—	1	22	4	27	—	—	9	1	10	—	—	2	1	3	—
—	39	1	4	44	—	—	39	14	53	—	1	—	3	4	—
—	4	8	13	25	—	1	37	10	48	—	—	4	3	7	—
2	41	2	1	46	—	1	38	7	46	—	—	—	1	1	—
—	8	36	7	51	—	1	12	2	15	—	—	1	3	4	—
—	3	23	1	27	—	—	1	—	1	—	—	2	—	2	—
—	1	25	1	27	—	—	—	—	—	—	—	—	—	—	2
—	10	49	5	64	—	—	—	1	1	—	—	—	—	—	—
—	6	20	1	27	—	1	5	—	6	—	—	—	—	—	—
1	6	1	1	9	—	1	10	1	12	—	—	—	1	1	—
1	9	9	—	19	—	—	4	6	10	—	—	—	—	—	—
—	2	2	6	10	—	—	42	32	74	3	3	—	1	7	3
1	17	41	23	82	—	—	—	—	—	—	—	—	—	—	—
—	18	12	5	35	—	—	—	—	—	—	—	—	1	1	—
—	20	17	3	40	—	—	—	—	—	—	—	—	—	—	—
—	1	1	1	3	—	—	—	—	—	—	—	—	—	—	—
—	—	9	3	12	—	—	—	—	—	—	—	—	—	—	1
1	19	13	6	39	—	—	—	—	—	—	—	—	—	—	1
2	16	13	2	33	—	—	—	—	—	—	—	—	—	—	—
—	5	13	—	18	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	1	4	1	6	—	—	—	—	—	—	—	—	—	—	—
—	20	10	—	30	—	—	—	—	—	—	—	—	—	—	—
—	25	23	3	51	—	—	—	—	—	—	—	—	—	—	—
—	5	27	13	45	—	—	—	—	—	—	—	—	—	—	—
—	2	5	5	12	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

A-11. 1956, John N. Cobb (U.S.)

Date		Lat.(°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of shackles of varying mesh size[1]				Sockeye				
						$2^1/_2$	$3^1/_4$	$4^1/_2$	$5^1/_4$	$2^1{}_2$	$3^1/_4$	$4^1{}_2$	$5^1{}_4$	Total
July	18	46—17	126—58W	6.2	15.8	—	4	5	5	—	—	—	—	
	19	45—05	126—54W	8.0	16.7	—	4	5	5	—	—	—	—	—
	21	46—45	130—47W	8.5	15.0	—	3	5	6	—	—	—		
	23	50—01	133—58W	9.0	13.3	—	3	5	6	—	—	—	2	2
	24	50—00	137—00W	8.0	12.8	—	3	5	6		—	1	1	2
	25	50—00	140—00W	8.2	12.2	—	3	5	6	—	—	—	1	1
	26	48—40	140—00W	8.5	12.2	—	3	5	6	—	—	—	—	
	27	47—20	140—00W	9.5	13.1	—	3	5	6	—	—	—	—	—
	28	46—00	140—00W	8.0	14.4	—	3	5	6	—	—		—	—
	30	46—00	133—30W	8.5	14.4	—	3	5	6		—	—	—	—
Aug.	1	46—00	127—28W	8.0	16.1	—	3	5	6	—		—	—	
	2	45—58	125—49W	7.5	16.1	—	3	5	6	—		—	—	
	7	46—12	125—13W	8.2	16.9	—	3	7	8	—	—	—	—	—
	9	41—50	126—24W	8.5	16.1	—	3	3	2	—		—	—	—
	15	45—00	135—00W	10.2	17.2	—	3	7	8	—	—	—	—	—
	17	45—00	140—00W	10.5	16.8	—	3	7	8	—	—	—	—	—
	19	46—00	145—00W	12.7	15.0	—	3	3	2	—	—	—	—	—
	20	47—20	145—00W	10.2	14.1	—	3	7	8	—	—	—	—	—
	21	48—40	145—00W	11.5	13.6	—	3	7	8	—	—	—	—	—
	22	50—00	145—00W	10.5	13.6	—	3	7	8	—	—	—	—	—
	23	49—59	141—48W	10.0	14.6	—	3	7	8		—	—		—
	24	49—58	139—00W	11.2	14.6	—	3	7	8	—	—	—	—	—
	25	49—00	137—07W	9.7	15.0	—	3	7	8	—	—	—	—	—
	26	48—06	135—10W	9.7	16.4	—	3	7	8	—	—	—	—	—
	27	49—06	133—11W	10.2	16.1	—	3	7	8	—	—	—	—	—
	28	50—01	131—31W	10.5	16.5	—	3	7	8	—	—	—	—	—
	29	50—00	129—30W	10.7	16.4	—	3	7	8	—	—	—	—	—

[1] Mesh size in inches.

Chum					Pink					Coho					Chinook
2 1/2	3 1/4	4 1/2	5 1/4	Total	2 1/2	3 1/4	4 1/2	5 1/4	Total	2 1/2	3 1/4	4 1/2	5 1/4	Total	Total
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	1	—	1	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

A-12. 1956, Mitkof (U.S.)

Date	Lat.(°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of shackles of varying mesh size[1]				Sockeye				
					2½	3¼	4½	5¼	2½	3¼	4½	5¼	Total
May 17	48—00	129—59W	15.0	10.9	2	2	4	4	—	—	—	1	1
22	48—02	140—03W	64.0	8.3	2	2	4	4	1	2	4	2	9
25	47—58	150—00W	17.0	6.8	2	2	4	4	3	1	2	3	9
28	50—00	155—04W	18.0	5.3	2	2	4	4	—	—	6	—	6
June 15	51—00	175—00 E	14.7	5.5	3	3	6	6	1	2	2	11	16
16	50—00	175—00 E	15.7	5.1	3	3	6	6	17	15	38	21	91
19	43—12	175—00 E	15.5	11.9	2	2	4	4	—	—	—	—	
22	43—11	175—00W	17.5	12.5	2	2	4	4	—	—	—	—	
26	50—00	175—05W	16.7	6.8	2	2	4	4	1	1	10	—	12
July 6	53—00	180	16.0	6.6	2	2	4	4	—	2	1	5	8
7	54—00	180	15.0	6.9	2	2	4	4	1	1	13	7	22
8	55—00	180	15.7	7.0	2	2	4	4	3	3	6	1	13
9	56—00	180	16.2	7.4	2	2	4	4	2	—	3	2	7
10	57—00	180	16.7	7.7	2	2	4	4	1	—	1	4	6
11	58—00	180	17.0	7.1	2	2	4	4	1	3	1	3	8
13	60—00	175—00W	15.5	7.9	3	3	6	6	—	—	3	—	3
14	59—00	175—00W	15.0	7.3	3	3	6	6	—	—	—	—	
15	58—00	175—00W	15.0	9.5	3	3	6	6	1	2	4	7	14
17	57—00	175—00W	35.5	8.5	3	3	6	6	—			—	
Aug. 3	54—59	174—55W	15.2	9.2	3	3	6	6	—	—	5	4	9
4	53—59	174—59W	15.0	9.5	3	3	6	6	—	—	—	—	
5	52—57	174—59W	15.0	10.3	3	3	6	6	—	—	1	1	2
8	50—59	174—57W	16.7	11.5	3	3	6	6	1	17	49	20	87
9	49—59	174—58W	17.2	12.4	3	3	6	6	—	1	2	1	4
10	49—00	175—00W	16.2	13.5	3	3	6	6	—	1	—	—	1
11	48—00	175—00W	15.7	13.5	3	3	6	6	—	—	—	—	
12	47—00	175—00W	16.0	14.2	3	3	6	6	—	—	—	—	
14	47—00	180	16.5	17.1	3	3	6	6	—	—	—	—	
15	48—00	179—54W	13.0	15.1	3	3	6	6	—	—	—	—	
16	49—00	179—57W	15.5	13.4	3	3	6	6	—	—	—	—	
17	50—00	180	5.5	13.8	3	3	6	6	—	—	—	—	
23	51—00	180	14.2	7.1	3	3	6	6	5	66	70	21	162
25	51—00	175—00 E	14.0	9.7	3	3	6	6	8	48	140	39	235
26	50—00	175—00 E	15.2	11.2	3	3	6	6	1	2	7	3	13
27	49—00	175—00 E	15.2	12.1	3	3	6	6	—	—	—	—	—
28	48—00	175—00 E	15.2	13.7	3	3	6	6	—	—	—	—	
Sept. 2	47—00	180	12.0	11.7	3	3	6	6	—	—	—	—	—
3	48—00	180	15.7	11.7	3	3	6	6	—	—	—	—	
4	49—00	180	16.0	11.6	3	3	6	6	—	—	—	—	
5	50—00	180	21.0	10.6	3	3	6	6	—	—	—		—
16	54—00	160—00W	16.2	10.6	3	3	6	6	—	—	—	1	1

[1] Mesh size in inches.

Chum					Pink					Coho					Chinook
$2^1/_2$	$3^1/_4$	$4^1/_2$	$5^1/_4$	Total	$2^1/_2$	$3^1/_4$	$4^1/_2$	$5^1/_4$	Total	$2^1/_2$	$3^1/_4$	$4^1/_2$	$5^1/_4$	Total	Total
—	—	—	—	—	—	—	—	—	—	—	—	1	—	1	—
—	1	4	2	7	—	—	—	—	—	—	—	1	—	1	1
—	—	4	1	5	—	—	—	—	—	—	—	—	—	—	2
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	8	22	15	45	—	3	6	—	9	—	—	—	—	—	—
—	29	5	8	42	—	1	2	—	3	—	—	1	—	1	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1	—	1	1	3	—	—	—	—	—	—	—	—	—	—	1
1	2	6	—	9	—	—	—	—	—	—	—	—	—	—	—
7	14	15	6	42	—	—	1	—	1	—	—	—	—	—	—
58	52	17	3	130	—	—	1	—	1	—	—	—	—	—	1
66	15	4	3	88	—	—	—	—	—	—	—	—	—	—	7
11	6	3	1	21	—	—	—	—	—	—	—	—	—	—	2
—	36	28	6	70	—	—	—	—	—	—	—	—	—	—	—
—	—	4	6	10	—	—	—	—	—	—	—	—	—	—	—
—	—	1	7	8	—	—	—	—	—	—	—	—	—	—	—
18	34	18	15	85	—	—	—	—	—	—	—	—	—	—	3
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	2	3	5	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2	5	21	8	36	—	—	—	—	—	—	—	—	—	—	—
—	5	10	14	29	—	—	—	—	—	—	—	—	—	—	2
3	11	34	10	58	—	—	—	—	—	—	—	—	—	—	2
—	1	5	4	10	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	4	4	—	—	—	—	—	—	—	—	—	—	—
—	—	32	18	50	—	—	—	—	—	—	—	—	—	—	—
—	3	16	8	27	—	—	—	1	1	1	—	—	—	1	6
1	—	41	46	88	—	—	—	—	—	—	—	—	—	—	—
—	1	12	14	27	—	—	—	—	—	—	—	—	—	—	5
—	—	15	6	21	—	—	—	—	—	—	—	—	—	—	1
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	2	6	8	—	—	—	—	—	—	—	—	—		
—	—	17	15	32	—	—	—	—	—	—	—	—	—	—	
—	2	3	2	7	—	—	—	—	—	—	—	—	—	—	—

A-13. 1956, Paragon (U.S.

Date	Lat.(°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of shackles of varying mesh size[1]				Sockeye				
					2½	3¼	4½	5¼	2½	3¼	4½	5¼	Total
July 12	59—00	140—00W	16.0	11.6	3	4	7	4	—	—	6	5	11
13	59—00	145—00W	14.7	12.4	3	4	7	4	—	4	3	5	12
15	59—00	150—00W	14.7	12.0	3	4	7	4	—	—	2	—	2
20	55—00	155—00W	17.0	10.4	3	4	7	4	5	7	13	20	45
21	54—00	155—00W	15.0	10.5	3	4	7	4	—	7	19	18	44
22	53—00	155—00W	15.2	10.5	3	4	7	4	—	2	8	3	13
23	52—00	155—00W	16.2	9.6	3	4	7	4	1	6	11	8	26
24	51—00	155—00W	15.5	9.4	3	4	7	4	5	11	18	3	37
25	50—00	155—00W	15.0	9.6	3	4	7	4	—	1	1	1	3
26	49—00	155—00W	16.7	9.7	3	4	7	4	—	2	—	—	2
27	48—01	154—53W	15.7	11.2	3	4	7	4	—	2	—	—	2
28	46—54	155—00W	15.0	12.4	3	4	7	4	—	—	—	—	—
29	45—51	154—53W	15.2	12.6	3	4	7	4	—	—	—	—	—
31	45—59	160—03W	19.5	14.3	3	4	7	4	—	—	—	—	—
Aug. 1	47—00	160—00W	13.7	12.3	3	4	7	4	—	—	—	—	—
2	48—00	160—00W	17.0	11.7	3	4	7	4	—	—	—	—	—
3	48—58	160—00W	16.5	11.2	3	4	7	4	—	2	—	—	2
4	50—00	160—00W	14.5	10.4	2	2	5	3	—	—	10	—	10
5	51—00	160—10W	14.2	10.3	2	2	5	3	—	2	3	1	6
6	51—57	160—00W	17.0	10.3	3	4	7	4	—	2	9	3	14
7	53—02	160—00W	13.7	10.4	2	2	5	3	1	—	17	5	23
8	54—00	160—00W	17.2	12.1	3	4	7	4	1	1	12	7	21
19	52—00	170—00W	14.2	9.9	3	4	7	4	12	12	2	—	26
20	51—00	170—00W	13.0	10.4	2	2	5	3	2	6	11	4	23
21	50—00	170—00W	15.0	10.8	2	2	5	3	—	9	2	—	11
22	49—00	170—00W	14.0	12.0	2	2	5	3	—	—	—	—	—
22*	48—00	170—00W	5.0	12.0	2	2	5	3	—	—	—	—	—
25*	46—00	170—00W	5.0	12.0	3	3	7	4	—	—	—	—	—
27	46—00	165—00W	12.5	12.2	2	2	5	3	—	—	—	—	—
28	47—00	165—00W	8.2	12.0	2	2	5	3	—	—	—	—	—
29	48—00	165—00W	8.5	11.0	2	2	5	3	—	—	—	—	—
30	49—00	165—00W	12.7	10.3	2	2	5	3	—	—	—	—	—
31	50—00	165—00W	12.5	9.7	3	3	7	4	—	1	2	1	4
Sept. 2	52—00	165—00W	9.7	9.6	3	3	7	4	—	7	11	6	24
3	53—00	165—00W	11.2	9.3	3	3	7	4	3	—	8	3	14
7	53—00	165—00W	7.5	10.2	3	3	7	4	—	—	1	1	2
8	52—00	165—00W	8.5	9.7	3	3	7	4	1	—	2	1	4
10	51—00	165—00W	11.2	10.4	3	3	6	4	—	1	3	1	5
11	50—00	165—00W	7.7	10.3	3	3	6	4	—	—	1	—	1
12	49—00	165—00W	8.5	11.0	3	3	6	4	—	—	—	—	—
14	49—00	160—00W	15.5	11.1	3	3	6	4	—	—	—	—	—
15*	49—00	155—00W	11.2	12.1	3	3	6	4	—	—	—	—	—
17	49—00	150—00W	12.0	13.3	3	3	6	4	—	—	—	—	—
22	49—00	135—00W	12.7	15.3	3	3	7	4	—	—	—	—	—
24	50—00	130—00W	15.7	15.3	2	2	6	3	—	—	—	—	—

* Day set. [1] Mesh size in inches.

Chum					Pink					Coho					Chinook
2¹/₂	3¹/₄	4¹/₂	5¹/₄	Total	2¹/₂	3¹/₄	4¹/₂	5¹/₄	Total	2¹/₂	3¹/₄	4¹/₂	5¹/₄	Total	Total
—	—	8	10	18	—	9	48	—	57	—	—	5	1	6	—
—	33	52	52	137	—	10	6	4	20	—	—	—	2	2	—
—	—	—	—	—	—	—	3	—	3	—	—	—	—	—	—
—	5	68	18	91	—	1	23	9	33	—	—	3	3	6	—
—	2	26	16	44	—	1	6	1	8	—	—	1	3	4	—
—	—	7	1	8	—	—	—	—	—	—	—	—	1	1	1
—	—	16	3	19	—	—	3	2	5	1	—	—	—	1	—
—	3	2	5	10	—	—	1	—	1	—	—	1	3	4	—
—	8	16	5	29	—	—	1	—	1	—	—	—	6	6	1
1	17	12	3	33	—	—	—	—	—	—	—	—	1	1	—
—	1	—	—	1	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	3	2	5	—	—	—	—	—	—	—	—	—	—	—
—	1	20	6	27	—	—	—	—	—	—	—	—	3	3	1
—	—	20	8	28	—	—	—	—	—	—	—	—	—	—	—
—	6	21	5	32	—	—	—	—	—	—	—	—	1	1	—
—	1	26	6	33	—	—	—	—	—	—	—	—	—	—	—
—	2	7	1	10	—	—	—	—	—	—	—	—	—	—	1
—	5	51	24	80	—	—	3	—	3	—	—	—	—	—	—
—	1	3	1	5	—	—	—	—	—	—	—	—	—	—	—
—	—	18	3	21	—	—	—	—	—	—	—	—	—	—	—
—	—	27	13	40	—	—	—	—	—	—	—	—	—	—	1
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	6	1	7	—	—	—	—	—	—	—	—	—	—	—
—	2	39	10	51	—	—	—	—	—	—	—	—	—	—	—
—	7	22	2	31	—	—	—	—	—	—	—	—	—	—	—
—	4	7	6	17	—	—	—	2	2	—	—	1	1	2	1
—	—	4	—	4	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1	—	15	—	16	—	—	—	—	—	—	—	—	—	—	—
—	—	8	2	10	—	—	—	—	—	—	—	—	—	—	—
—	—	12	8	20	—	—	—	—	—	—	—	—	—	—	—
—	—	4	—	4	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

A-14. 1956, Tordenskjold (U.S.)

Date	Lat.(°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of shackles of varying mesh size[1]				Sockeye				
					2½	3¼	4½	5¼	2½	3¼	4½	5¼	Total
May 25	58—00	150—00W	11.0	4.7	3	3	6	6	—	—	—	2	2
31	53—00	165—00W	9.5	4.1	3	3	6	6	—	2	8	29	39
June 7	55—00	165—00W	11.5	3.1	3	3	6	6	—	—	3	59	62
8	56—00	165—00W	11.7	2.5	3	3	6	6	—	—	1	1	2
9	57—00	165—00W	12.2	1.3	3	3	6	6	—	—	—	2	2
10*	57—17	159—15W	6.5	0.5	3	3	6	6	—	—	—	—	—
11	57—00	160—00W	12.0	2.7	3	3	6	6	—	—	—	3	3
13	58—00	165—00W	11.5	2.2	3	3	6	6	—	—	—	2	2
14	59—00	165—00W	11.5	1.9	3	3	6	6	—	—	—	1	1
16	60—00	170—00W	9.5	1.2	3	3	6	6	—	—	—	1	1
17	59—00	170—00W	11.5	2.2	3	3	6	6	—	—	—	1	1
18	58—00	170—00W	11.2	3.7	3	3	6	6	—	—	—	1	1
20	56—00	170—00W	11.5	5.7	3	3	6	6	8	35	376	498	917
21	55—00	170—00W	11.7	7.0	3	3	6	6	6	37	329	307	679
25	54—00	170—00W	11.7	7.2	3	3	6	6	—	4	23	56	83
July 29	54—00	169—58W	12.0	7.9	3	3	6	6	—	—	—	1	1
30	55—00	170—02W	12.2	8.2	3	3	6	6	—	—	—	1	1
31	55—59	170—02W	12.0	7.9	3	3	6	6	—	—	1	—	1
Aug. 2	58—00	170—00W	12.0	6.6	3	3	6	6	—	—	1	3	4
3	59—00	170—00W	11.7	6.9	3	3	6	6	—	—	—	—	—
4	59—59	170—01W	12.0	8.4	3	3	6	6	—	—	—	—	—
5	59—36	167—27W	11.0	6.9	3	3	6	6	—	—	1	1	2
6	58—56	165—12W	11.2	6.8	3	3	6	6	—	—	—	—	—
7	57—57	165—05W	12.0	8.5	3	3	6	6	—	—	1	—	1
8	58—00	162—32W	10.7	8.4	3	3	6	6	—	—	—	—	—
9	58—00	159—57W	11.5	10.4	3	3	6	6	—	—	—	1	1
11	56—57	160—04W	11.0	11.5	3	3	6	6	—	1	1	—	2
12	57—05	162—22W	12.2	10.9	3	3	6	6	—	—	—	—	—
13	57—04	164—58W	11.5	10.5	3	3	6	6	—	—	1	—	1
14	56—04	164—56W	11.7	10.8	3	3	6	6	—	—	4	7	11
Sept. 12	54—00	169—00W	11.0	6.4	3	3	6	6	—	—	—	—	—
14	55—00	170—00W	12.0	8.3	3	3	6	6	—	—	—	1	1
15	55—58	170—01W	12.0	7.6	3	3	6	6	—	—	—	—	—
16	57—00	170—00W	10.5	6.7	3	3	6	6	—	—	—	—	—
17	58—01	169—58W	12.2	6.4	3	3	6	6	—	—	—	1	1
19	57—00	165—00W	11.0	4.6	3	3	6	6	—	—	—	—	—
21	55—01	165—04W	12.7	7.1	3	3	6	6	—	—	—	—	—

* Day set.

[1] Mesh size in inches.

Chum					Pink					Coho					Chinook
2½	3¼	4½	5¼	Total	2½	3¼	4½	5¼	Total	2½	3¼	4½	5¼	Total	Total
—	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—
—	—	7	27	34	—	—	—	—	—	—	—	—	—	—	2
—	—	1	16	17	—	—	—	—	—	—	—	—	—	—	—
—	—	3	12	15	—	—	—	—	—	—	—	—	—	—	1
—	—	—	14	14	—	—	—	—	—	—	—	—	—	—	—
—	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—
—	—	—	1	1	—	—	—	—	—	—	—	—	—	—	1
—	—	8	37	45	—	—	3	1	4	—	—	—	—	—	—
—	1	37	88	126	—	—	2	1	3	—	—	—	—	—	1
—	—	4	15	19	—	—	1	1	2	—	—	—	—	—	—
—	—	10	47	57	—	—	5	—	5	—	—	—	—	—	—
—	—	4	27	31	—	1	2	2	5	—	—	—	—	—	1
—	—	14	48	62	—	—	5	—	5	—	—	—	—	—	3
—	1	20	46	67	—	1	6	2	9	—	—	—	—	—	1
—	—	1	18	19	—	—	—	—	—	—	—	—	—	—	—
—	—	1	1	2	—	—	1	—	1	—	—	—	1	1	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	2	7	9	—	—	—	—	—	—	—	—	—	—	—
—	—	—	5	5	—	—	—	—	—	—	—	—	1	1	—
—	—	8	23	31	—	—	—	—	—	—	—	1	—	1	1
—	—	3	3	6	—	—	—	—	—	—	—	—	—	—	—
—	—	—	11	11	—	—	—	1	1	—	—	—	—	—	—
—	—	2	2	4	—	—	—	—	—	—	—	—	—	—	—
—	—	4	7	11	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	2	4	6	8
—	—	—	1	1	—	—	—	—	—	—	—	1	—	1	1
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	1	1	—	—	—	—	—	—	—	—	1	1	2
—	—	1	2	3	—	—	—	—	—	—	—	2	1	3	—
—	—	1	5	6	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	2	10	12	—	—	—	—	—	—	—	—	—	—	1
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

A-15. 1957, Fort Ross (Canada)

Date	Lat.(°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of shackles of varying mesh size[1]				Sockeye				
					2½	3¼	4½	5¼	2½	3¼	4½	5¼	Total
May 19	55—00	135—00W	10.0	8.2	3	3	4	10	—	—	—	3	3
20*	52—30	135—00W	9.0	9.0	3	3	4	10	—	—	—	-	-
21	52—30	135—00W		9.0	3	3	4	10	—	—	—	—	-
22*	55—00	135—00W	8.0	9.0	3	3	4	10	—	—	—	1	1
23	55—00	135—00W	14.0	8.2	3	3	4	10	—	—	—	2	2
June 8	50—00	135—00W	7.0	13.8	5	6	18	6	1	6	21	3	31
9*	50—00	135—00W	8.5	13.8	5	6	18	5	—	8	39	7	54
10	50—00	135—00W	7.0	12.9	5	6	18	4	1	11	51	-	63
14	50—00	145—00W	8.0	9.0	5	6	18	4	3	27	7	1	38
21	50—00	155—00W	8.5	8.4	5	5	16	4	2	4	5	—	11
22*	50—00	155—00W	9.0	8.3	5	5	16	4	2	1	1	—	4
23	50—00	155—00W	8.5	9.0	5	5	16	4	21	38	5	2	66
24	50—00	155—00W	8.5	8.3	5	5	16	4	—	—	2	-	2
28	50—00	145—00W	7.0	9.7	5	5	15	1	1	3	3	-	7
30	50—00	145—00W	7.5	10.0	5	5	15	1	11	2	5	-	8
July 2	50—00	138—08W	8.0	11.0	5	5	15	1	—	4	28	4	36
3	50—00	135—00W	8.5	11.7	5	5	15	1	—	1	18	1	20
20	51—00	135—00W	9.0	13.5	5	6	18	6	—	11	51	58	120
21	51—00	135—00W	9.0	13.4	5	6	18	6	1	1	2	3	7
24	51—00	145—00W	—	12.1	5	6	18	6	—	—	—	-	-
26	51—00	145—00W	—	11.5	5	6	18	6	—	—	—	-	-
28	51—00	155—00W	10.0	11.9	5	6	18	6	1	1	—	-	2
29	52—00	155—00W	10.0	11.8	5	6	18	6	—	2	—	-	2
30	52—00	155—00W	10.0	11.1	5	6	18	6	17	—	3	2	22
31	52—00	155—00W	10.0	11.7	5	6	18	6	6	1	—	2	9
Aug. 2	52—00	145—00W	9.5	13.0	5	6	18	6	—	—	—	-	-
4	52—00	145—00W	9.5	13.3	5	6	18	6	—	1	—	2	3
6	52—00	135—00W	8.5	13.8	5	6	18	6	—	—	—	—	-
7	52—00	135—00W	—	13.7	5	6	18	6	—	—	—	—	-
8	52—00	134—00W	10.5	15.0	5	6	18	6	—	—	—	—	-
18	52—08	133—25W	—	15.1	5	6	18	6	—	—	—	-	-
19	52—30	135—00W	—	15.9	5	6	18	6	—	—	—	—	—
22	51—00	140—00W	—	14.4	5	6	18	6	—	—	—	—	—
25	49—05	134—24W	—	15.4	5	6	18	6	—	—	—	—	—
26	48—55	132—42W	—	15.8	5	6	18	6	—	—	—	—	—
27	48—50	131—06W	—	15.7	5	6	18	6	—	—	—	—	—
28	48—40	129—32W	—	16.7	5	6	18	6	—	—	—	-	-

* Day set.

[1] Mesh size in inches.

Chum					Pink					Coho					Chinook				
$1/_2$	$3^1/_4$	$4^1/_2$	$5^1/_4$	Total	$2^1/_2$	$3^1/_4$	$4^1/_2$	$5^1/_4$	Total	$2^1/_2$	$3^1/_4$	$4^1/_2$	$5^1/_4$	Total	$2^1/_2$	$3^1/_4$	$4^1/_2$	$5^1/_4$	Total
—	-	1	4	5	—	–	—	–	–	—	—	—	—	–	–	—	—	—	—
—	—	—	1	1	—	—	—	—	—	—	—	1	—	1	—	—	—	—	—
—	—	—	—	–	—	—	—	–	–	—	—	—	-	-	—	–	—	—	—
—	–	—	1	1	—	—	–	—	—	—	–	–	–	–	–	—	–	—	—
2	1	7	48	58	—	—	—	—	—	1	—	—	1	2	—	—	—	—	—
6	27	13	—	46	6	10	2	—	18	10	18	78	9	115	—	-	—	-	—
10	8	15	3	36	—	8	2	2	12	—	11	34	5	50	—	–	—	–	—
15	8	9	—	32	2	2	2	—	6	1	5	17	—	23	–	–	—	–	—
1	7	4	—	12	—	4	11	2	17	—	4	13	7	24	-	-	–	—	—
—	-	6	1	7	—	1	3	—	4	—	—	1	—	1	—	-	–	—	—
—	1	5	—	6	1	1	1	—	3	1	—	—	1	2	—	—	1	—	1
1	1	9	—	11	1	4	8	—	13	—	—	6	2	8	—	—	1	—	1
—	–	–	–	—	—	—	-	–	—	–	–	2	—	2	—	—	–	—	—
2	8	4	—	14	—	—	8	2	10	—	1	1	—	2	—	—	–	—	—
2	27	4	1	34	—	4	16	—	20	—	1	14	2	17	-	—	—	—	–
—	1	1	—	2	—	—	1	—	1	-	–	–	–	–	—	—	—	–	—
—	1	12	—	13	—	—	12	—	12	–	–	–	—	—	–	—	–	—	—
—	—	—	—	—	—	—	1	1	2	–	–	–	—	—	—	—	–	—	–
—	–	–	–	–	–	—	—	–	—	—	—	—	—	–	–	–	—	–	—
—	—	—	—	-	—	–	—	—	–	–	—	—	—	—	—	—	–	—	–
—	—	—	—	-	—	—	—	—	—	—	-	-	–	–	—	—	—	–	–
3	2	—	1	6	—	—	–	—	-	—	—	-	–	–	—	–	—	—	—
—	1	—	2	3	—	—	–	—	-	–	–	–	–	–	—	-	—	—	–
2	-	—	—	2	—	-	–	—	–	–	–	–	–	–	—	—	—	—	—
1	9	4	2	16	—	—	-	–	—	-	-	-	—	—	—	–	—	—	—
6	5	—	—	11	—	—	—	–	—	—	—	—	–	–	—	—	—	—	—
3	5	2	4	14	—	—	—	1	1	—	—	—	1	1	—	—	—	—	—
—	—	2	3	5	—	—	—	—	—	—	—	—	1	1	-	—	—	—	—
—	—	–	–	—	—	–	—	—	—	—	—	—	—	–	—	—	—	—	—
—	—	—	2	2	—	—	—	—	—	–	—	—	—	–	—	—	—	—	—
—	—	—	—	—	—	—	—	—	-	—	—	—	—	-	-	-	—	—	—
—	—	-	—	—	—	—	—	—	-	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	-	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
-	-	-	-	-	-	–	-	–	—	–	-	—	–	–	-	—	—	–	–

A-16. 1957, Key West II (Canada

Date		Lat.(°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of shackles of varying mesh size[1]				Sockeye				
						2 1/2	3 1/4	4 1/2	5 1/4	2 1/2	3 1/4	4 1/2	5 1/4	Total
May	13	47—39	126—46W	10.0	11.3	3	3	4	11	—	—	—	—	—
	14*	46—12	129—20W	—	11.3	3	3	4	11	—	—	—	—	—
	15	46—12	129—20W	9.5	11.1	3	3	4	11	—	—	—	—	—
	16	45—00	131—15W	—	11.4	3	3	4	11	—	—	—	—	—
	17	43—54	133—13W	—	11.3	3	3	4	11	—	—	—	—	—
	18	44—04	134—40W	—	10.4	3	2	3	9	—	—	—	—	—
	26	44—56	133—38W	9.5	11.9	3	2	3	9	—	—	—	—	—
	27	44—53	136—10W	—	11.5	3	2	3	9	—	—	—	—	—
	28	47—00	136—07W	9.5	10.7	3	2	3	9	—	—	—	—	—
	29	48—00	133—12W	9.5	10.8	3	2	3	9	—	—	1	—	1
	30	48—12	130—19W	—	11.9	3	2	3	9	—	—	—	—	—
June	14	54—53	134—22W	9.0	10.5	6	6	18	6	—	1	19	—	20
	15	55—00	135—00W	9.5	10.7	6	6	18	6	—	2	32	4	38
	29	55—00	145—00W	11.0	10.5	6	6	18	6	—	1	9	1	11
July	1	55—00	153—17W	10.5	10.5	6	6	18	6	—	—	39	—	39
	3	55—00	155—00W	10.0	10.0	6	6	18	6	18	5	90	12	125
	8	58—00	145—00W	10.0	13.3	6	6	18	6	—	—	41	18	59
	9	58—00	145—00W	9.0	13.0	6	6	18	6	1	—	16	1	18
	9*	58—00	145—00W	6.0	13.0	—	—	—	—	—	—	—	—	—
	10	58—00	145—00W	10.0	13.0	6	6	17	6	—	—	—	—	36[2]
	11*	55—00	145—00W	9.5	12.5	—	—	—	—	—	—	—	—	—
	12	53—00	145—00W	9.5	12.5	6	6	17	6	—	—	—	—	10[2]
	31	55—00	135—00W	11.0	15.2	7	7	18	9	—	—	14	3	17
Aug.	1	55—00	135—00W	10.5	15.2	7	7	18	9	—	—	12	3	15
	3	55—07	142—40W	10.0	14.8	7	7	18	9	—	—	1	—	1
	8	55—00	135—00W	10.0	14.4	7	7	18	9	—	—	1	1	2
	16	55—00	145—00W	10.0	15.0	7	7	18	9	—	—	2	—	2
	18	55—03	151—30W	11.0	15.3	7	7	18	6	1	7	3	—	11
	19	55—00	152—56W	10.0	14.4	7	7	18	6	2	8	6	—	16
	22	58—00	145—00W	9.0	15.5	7	7	18	6	—	—	2	—	2

* Day set.

[1] Mesh size in inches.

[2] Mesh sizes within which fish were caught are not known.

[3] Includes five pink salmon caught in unknown mesh sizes.

Chum					Pink					Coho					Chinook				
1/2	3 1/4	4 1/2	5 1/4	Total	2 1/2	3 1/4	4 1/2	5 1/4	Total	2 1/2	3 1/4	4 1/2	5 1/4	Total	2 1/2	3 1/4	4 1/2	5 1/4	Total
—	—	—	—	—	—	—	—	—	—	—	—	1	1	2	1	—	—	—	1
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1	—	—	—	1	1	—	—	1	2	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1	—	—	—	1	3	—	—	—	3	—	—	—	—	—	—	—	—	—	—
1	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	10	182	17	209	—	—	12	—	12	2	—	20	—	22	—	—	—	—	—
2	1	303	47	353	—	1	21	1	23	1	1	21	2	25	—	—	—	—	—
—	27	53	—	80	—	—	9	—	9	—	—	16	1	17	—	—	1	—	1
—	1	23	—	24	—	—	10	1	11	—	—	2	—	2	—	—	—	—	—
3	3	57	1	64	1	—	7	1	9	—	—	—	—	—	—	—	—	—	—
—	4	14	3	21	—	1	7	1	9	—	—	—	—	—	—	—	—	—	—
—	13	56	2	71	—	1	18	—	19	—	3	9	—	12	—	—	—	—	—
—	—	1	—	1	—	—	1	—	1	—	—	—	—	—	—	—	—	—	—
—	—	—	—	40[2]	—	2	8	8	24[3]	—	—	5	3	8	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	25[2]	—	—	—	—	117[2]	—	—	—	—	5[2]	—	—	—	—	—
—	—	3	—	3	—	1	27	17	45	—	—	2	—	2	—	—	—	—	—
—	—	2	1	3	—	5	44	7	56	—	—	3	—	3	—	—	—	—	—
1	6	7	2	16	—	—	—	1	1	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	1	4	5	—	—	—	—	—	—	—	—	—	—
—	3	16	—	19	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2	56	13	—	71	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
16	71	46	—	133	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1	65	60	2	128	—	1	—	—	1	—	—	—	—	—	—	—	—	—	—

A-17. 1957, ETSUZAN-MARU (Japan)

Date		Lat.(°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of shackles[1] of varying mesh size[2]				Sockeye				
						2½	3¼	4½	5¼	2½	3¼	4½	5¼	Total
May	21	51—15	169—02 E	13	4.0	1	1	3	1	—	1	12	4	17
	22	51—58	169—30 E	16	4.5	1	1	3	1	—	1	16	6	23
	25	52—31	168—27 E	10	4.4	1	1	3	1	—	—	6	2	8
	26	52—02	169—26 E	10	4.2	1	1	3	1	—	—	20	3	23
	27	51—28	169—55 E	9	4.6	1	1	3	1	—	—	6	2	8
	31	49—02	167—25 E	10	3.9	1	1	3	1	—	—	9	1	10
June	1	50—04	166—47 E	9	3.5	1	1	3	1	—	3	12	—	15
	5	52—56	170—32 E	11	4.5	1	1	3	1	—	—	5	—	5
	7	52—42	179—17 E	9	4.9	1	1	3	1	—	1	8	1	10
	9	52—42	178—26W	9	5.8	1	1	3	1	2	1	9	9	21
	11	52—37	177—51W	9	5.3	1	1	3	1	—	—	13	4	17
	12	52—36	176—11W	?	5.7	1	1	3	1	1	—	44	17	62
	13	52—42	176—00W	15	6.5	1	1	3	1	2	2	20	11	35
	15	54—51	178—00W	14	6.2	1	1	3	1	3	11	91	27	132
	21	55—20	169—20W	14	8.0	1	1	3	1	1	3	15	3	22
	23	55—56	168—44W	15	8.8	1	1	3	1	—	5	54	14	73
	24	56—30	168—44W	14	10.5	1	1	3	1	1	3	46	27	77
July	6	54—28	179—26W	15	7.9	1	1	3	1	24	4	3	—	31
	7	56—29	179—40 E	14	9.0	1	1	3	1	2	4	5	—	11
	8	57—01	179—59 E	14	9.2	1	1	3	1	1	2	7	—	10
	9	57—22	179—52W	14	9.1	1	1	3	1	—	—	3	—	3
	10	57—20	179—21 E	14	8.6	1	1	3	1	1	1	3	—	5
	13	53—09	171—19 E	14	8.1	1	1	3	1	—	8	8	2	18
	15	52—30	163—20 E	10	8.8	1	1	3	1	—	—	14	1	15
	16	52—40	162—25 E	15	9.0	1	1	3	1	1	—	5	2	8
	17	52—45	162—30 E	15	11.0	1	1	3	1	2	6	13	2	23
	19	52—55	162—46 E	15	11.7	1	1	3	1	2	3	8	1	14
	20	53—39	162—50 E	15	11.6	1	1	3	1	—	4	15	3	22
	21	52—30	162—48 E	12	10.7	1	1	3	1	—	1	4	3	8
	24	51—25	160—08 E	8	9.6	1	1	3	1	—	—	—	—	—
	25	51—58	160—52 E	14	9.1	4	4	3	1	1	2	1	4	8
	26	51—30	161—10 E	?	10.2	4	4	3	1	—	3	7	2	12
	27	52—02	160—00 E	15	9.9	4	4	3	1	1	3	—	—	4
	28	52—03	162—52 E	15	10.8	4	4	3	1	—	1	6	3	10
	29	52—22	164—04 E	15	10.7	4	4	3	1	1	6	21	3	31
	30	52—24	164—50 E	16	11.4	4	4	3	1	2	13	13	2	30
	31	52—13	165—39 E	15	11.8	4	4	3	1	—	11	8	1	20
Aug.	1	52—07	166—57 E	12	10.4	4	4	3	1	—	3	11	—	14

[1] Length of one shackle is 50 fathoms.

[2] Mesh size in inches.

Chum					Pink					Coho					Chinook				
$1/_2$	$3^1/_4$	$4^1/_2$	$5^1/_4$	Total	$2^1/_2$	$3^1/_4$	$4^1/_2$	$5^1/_4$	Total	$2^1/_2$	$3^1/_4$	$4^1/_2$	$5^1/_4$	Total	$2^1/_2$	$3^1/_4$	$4^1/_2$	$5^1/_4$	Total
—	—	11	2	13	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	8	1	9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	3	1	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	1	5	1	7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	15	7	22	—	—	—	1	1	—	—	—	—	—	—	—	—	—	—
—	—	9	—	9	—	2	12	1	15	—	—	—	—	—	—	—	—	—	—
—	—	10	3	13	—	—	5	—	5	—	—	—	—	—	—	—	—	—	—
1	—	10	—	11	—	—	1	—	1	—	—	—	—	—	—	—	—	—	—
—	2	1	—	3	—	1	9	1	11	—	—	—	—	—	—	—	—	—	—
—	5	1	1	7	—	19	47	6	72	—	—	—	—	—	—	—	—	—	—
—	—	2	—	2	—	—	2	—	2	—	—	—	—	—	—	—	—	—	—
—	4	7	1	12	—	12	21	1	34	—	—	—	—	—	—	2	1	—	3
—	—	7	—	7	—	21	74	—	95	—	—	—	—	—	—	—	—	—	—
—	—	1	—	1	—	2	31	2	35	—	—	—	—	—	—	—	—	—	—
—	—	1	—	1	—	—	14	1	15	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1	—	3	1	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
24	4	9	—	37	—	1	11	—	12	—	—	—	—	—	—	—	—	—	—
8	7	4	1	20	—	2	21	—	23	—	—	—	—	—	—	—	—	—	—
7	10	29	2	48	—	1	12	—	13	—	—	—	—	—	—	—	—	—	—
14	14	21	4	53	—	—	3	—	3	—	—	—	—	—	—	—	—	—	—
19	4	5	—	28	—	—	4	1	5	—	—	—	—	—	—	—	—	—	—
6	2	5	1	14	—	2	22	2	26	—	—	—	—	—	—	—	—	—	—
8	7	4	1	20	—	1	6	1	8	—	—	—	1	1	—	—	—	—	—
5	5	7	3	20	—	1	25	3	29	1	—	1	—	2	—	—	—	—	—
6	10	8	1	25	—	—	10	1	11	—	—	—	—	—	—	—	—	—	—
5	3	6	2	16	—	2	8	1	11	—	—	—	1	1	—	—	—	—	—
1	3	2	2	8	—	1	11	1	13	—	—	1	—	1	—	—	—	—	—
1	4	4	—	9	—	—	7	—	7	—	—	1	2	3	—	—	—	—	—
2	2	—	—	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
27	23	3	—	53	—	6	24	—	30	—	—	4	2	6	—	—	—	—	—
11	6	3	—	20	—	3	19	3	25	—	—	—	1	1	—	—	—	—	—
10	9	3	4	26	—	—	4	—	4	—	2	2	3	7	—	—	—	—	—
16	21	—	—	37	—	1	4	—	5	—	2	5	6	13	—	—	—	—	—
28	35	9	5	77	—	—	1	—	1	1	2	10	1	14	—	—	—	—	—
4	17	18	2	41	—	—	—	—	—	1	6	5	7	19	—	—	—	—	—
3	9	6	2	20	—	—	—	—	—	—	3	9	2	14	—	—	—	—	—
—	11	2	—	13	—	1	1	—	2	1	4	18	6	29	—	—	1	—	1

A-18. 1957, KANO-MARU (Japan)

Date	Lat.(°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of shackles of varying mesh size[1]				Sockeye				Total
					2½	3¼	4½	5¼	2½	3¼	4½	5¼	
May 18	48—00	165—00 E	13	3.2	1	1	3	1	—	—	—	9	9
19	48—02	167—22 E	17	3.4	1	1	3	1	—	2	26	2	30
21	48—08	167—40 E	13	3.8	1	1	3	1	—	1	25	2	28
23	49—15	167—56 E	15	3.9	1	1	3	1	—	—	7	5	12
24	49—13	169—00 E	10	3.6	1	1	3	1	—	—	12	—	12
25	49—45	170—24 E	14	5.1	1	1	3	1	—	—	17	5	22
June 1	49—37	171—00 E	14	5.9	1	1	3	1	—	—	7	3	10
6	49—55	175—02 E	13	5.4	1	1	3	1	—	4	7	—	11
8	50—05	179—56 E	?	5.9	1	1	3	1	—	—	2		2
10	49—05	179—50 E	9	6.3	1	1	3	1	4	—	—		4
11	50—15	179—30 E	?	6.1	1	1	3	1	2	—	—		2
12	50—20	179—34W	14	5.9	1	1	3	1	9	3	—		12
19	51—52	171—18W	10	7.5	1	1	3	1	—	—	5		5
20	50—30	170—18W	12	7.5	1	1	3	1	—	—	2	—	2
21	50—53	169—50W	12	8.6	1	1	3	1	—	5	2	1	8
22	51—11	169—28W	12	8.2	1	1	3	1	—	3	3	—	6
24	51—21	170—21W	?	7.8	1	1	3	1	—	3	3	—	6
27	55—16	176—55W	8	6.2	1	1	3	1	3	1	14	4	22
28	55—42	177—35W	7	6.6	1	1	3	1	—	1	2	2	5
29	55—16	176—55W	8	6.9	1	1	3	1	—	2	6	1	9
July 7	56—10	164—41W	8	11.0	1	1	3	1	1	1	10	4	16
8	56—08	166—30W	8	10.5	1	1	3	1	1	—	—		1
15	58—16	167—22 E	7	11.2	1	1	3	1	4	2	11	4	21
16	58—17	167—10 E	5	11.4	1	1	3	1	13	3	7	1	24
19	52—37	162—08 E	?	11.9	1	1	3	1	—	—	15	3	18
20	53—34	163—15 E	?	11.9	1	1	3	1	—	3	4	—	7
21	53—33	162—52 E	7	11.8	1	1	3	1	2	1	8	3	14
24	51—31	160—10 E	5	10.2	1	1	3	1	4	—	5	1	10
25	52—02	161—04 E	?	10.9	1	1	3	1	1	1	9		11
26	51—06	160—08 E	10	9.7	1	1	3	1	—	1	3	—	4
27	51—52	160—51 E	14	11.4	1	1	3	1	1	7	12	—	20
28	52—16	162—00 E	?	11.1	1	1	3	1	1	1	14	2	18
29	52—32	163—00 E	?	12.0	1	1	3	1	1	1	4	3	9
30	52—40	164—48 E	?	11.4	1	1	3	1	1	2	11		14
31	53—17	165—55 E	?	11.6	1	1	3	1	—	4	9	1	14
Aug. 2	53—30	167—14 E	?	10.6	1	1	3	1	—	1	6	—	7
4	52—50	168—45 E	?	10.3	1	1	3	1	1	2	13		16
5	53—57	166—23 E	?	11.0	1	1	3	1	1	5	17	1	24
6	53—54	164—32 E	?	13.8	1	1	3	1	1	3	15		19
8	53—51	163—03 E	?	13.9	1	1	3	1	1	5	12	2	20

[1] Mesh size in inches.

Chum					Pink					Coho					Chinook				
/2	3 1/4	4 1/2	5 1/4	Total	2 1/2	3 1/4	4 1/2	5 1/4	Total	2 1/2	3 1/4	4 1/2	5 1/4	Total	2 1/2	3 1/4	4 1/2	5 1/4	Total
—	1	6	2	9	—	6	4	—	10	—	—	—	—	—	—	—	—	—	—
—	1	10	4	15	—	1	2	—	3	—	—	—	—	—	—	—	—	—	—
—	—	9	3	12	—	—	1	2	3	—	—	—	—	—	—	—	—		—
-	-	3	—	3	—	—	-	—	—	—	-	—	—	—	—	—	—		—
—	—	6	—	6	—	4	2	—	6	—	—	—	—	—	—	—	—	—	—
—	1	10	5	16	—	—	11	—	11	—	—	—	—	—	—	—	—	—	—
—	2	9	—	11	—	2	17	—	19	—	—	—	—	—	-	-	—	—	—
—	—	8	—	8	—	2	30	3	35	—	—	—	—	—	—	—	—	—	—
—	1	2	—	3	—	17	31	—	48	—	—	—	—	—	—	—	—	—	—
—	—	3	—	3	—	16	19	—	35	—	—	—	—	—	—	—	—		—
—	2	6	—	8	—	6	15	—	21	—	-	—	—	-	—	—	—		—
—	1	—	—	1	—	3	7	—	10	—	—	—	—	—	-	—	—	—	—
—	2	6	—	8	—	5	58	—	63	—	—	—	—	—	—	—	—	—	—
—	1	3	—	4	—	5	39	—	44	—	—	—	—	—	—	—	—	—	—
—	1	5	1	7	—	—	15	—	15	—	—	—	—	—	—	—	—	—	—
—	1	—	—	1	—	1	9	—	10	—	—	—	—	—	—	—	—	—	—
2	4	—	3	9	1	2	14	1	18	—	—	—	—	—	—	—	—	—	—
—	2	4	3	9	—	2	54	6	62	—	—	—	—	—	—	—	—	—	—
—	—	1	—	1	—	12	160	4	176	—	—	—	—		—	—	—	—	—
1	1	6	1	9	—	2	49	3	54	—	—	—	—	—	—	-	—	—	—
—	—	15	10	25	—	—	1	—	1	—	—	—	—	—	—	—	1	—	1
—	—	1	1	2	—	—	2	—	2	—	—	2	—	2	—	-			-
—	—	3	—	3	—	—	100	8	108	—	—	—	—	—	1	—	—	—	1
10	7	5	1	23	—	17	85	17	119	—	—	—	—		—	—	—	—	—
9	3	6	1	19	—	—	15	1	16	—	—	—	—		—	-	—	—	—
4	3	4	1	12	—	1	7	—	8	—	—	2	—	2		—	—	—	
3	5	1	1	10	—	1	8	—	9	—	—	—	—	-	—	—	-	-	
10	4	4	1	19	—	—	6	—	6	—	—	—	—	—	—	—	3	—	3
6	5	8	2	21	—	—	10	2	12	—	—	3	4	7	—		—	—	—
3	7	2	2	14	—	1	22	1	24	—	1	5	1	7	—	—	—	—	—
2	4	10	2	18	-	1	9	1	11	—	1	4	1	6	-	—	—	—	—
3	6	8	1	18	—	—	1	—	1	—	—	9	2	11	—	—	1	—	1
2	5	8	1	16	—	—	1	—	1	—	—	1	1	2	—	—	—	—	—
1	3	8	1	13	—	—	—	—	—	—	—	2	1	3	—	—			-
1	2	7	—	10	—	—	—	—	—	—	—	2	1	3	—	—			
1	5	21	—	27	—	—	—	—	—	—	1	7	—	8	—	—	1	—	1
1	1	5	—	7	—	1	—	—	1	—	—	—	1	1	—	—	-		
1	2	7	—	10	—	—	—	—	—	—	—	3	1	4	—	—	—	—	—
3	1	7	1	12	—	—	—	—	—	—	1	3	—	4	—	—	—	—	—
4	9	6	1	20	—	—	—	—	—	—	—	2	—	2			—	—	—

A-19. 1957, Attu (U.S.)

Date	Lat.(°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of shackles of varying mesh size[1]				Sockeye				
					2½	3¼	4½	5¼	2½	3¼	4½	5¼	Total
May 28	50—00	175—00W	11.5	5.9	4	4	12	4	1	1	4	1	7
30	50—00	175—00W	15.0	5.9	4	4	12	4	1	1	6	—	8
31	50—00	175—00W	16.0	5.9	4	4	12	4	—	1	5	—	6
June 8	53—00	175—00W	14.5	5.8	4	4	12	4	1	5	30	16	52
9	53—01	175—03W	16.2	5.6	4	4	12	4	—	2	45	11	58
10	53—00	175—00W	14.2	5.7	4	4	12	4	—	1	55	12	68
15	56—00	175—00W	18.5	5.8	4	4	12	4	3	12	162	60	237
17	56—00	173—00W	11.5	6.9	4	4	12	4	1	8	123	55	187
18	56—00	170—00W	15.5	7.4	3	3	9	3	1	6	69	40	116
19	56—52	170—00W	16.2	7.0	3	3	9	3	—	—	46	22	68
20	56—00	170—00W	15.5	7.7	3	3	9	3	—	2	7	—	9
21	56—00	168—00W	10.5	7.9	3	3	9	3	1	2	50	10	63
22	55—00	168—00W	16.0	7.9	3	3	9	3	1	1	57	29	88
23	56—00	166—00W	12.0	9.1	3	3	9	3	—	3	8	8	19
24	55—00	166—00W	15.0	9.5	3	3	9	3	—	—	12	3	15
July 8	56—00	165—00W	17.0	10.4	4	4	12	4	—	—	2	—	2
9	56—00	165—00W	15.2	10.2	4	4	12	4	—	—	1	—	1
10	56—00	165—00W	10.5	10.6	4	4	12	4	—	—	14	6	20
15	54—00	160—00W	14.0	11.9	4	4	12	4	4	22	34	6	66
17	52—00	160—00W	14.5	10.2	4	4	12	4	—	15	85	9	109
19	50—00	160—00W	16.0	10.3	4	4	12	4	—	4	4	—	8
21	50—00	165—00W	16.5	10.0	4	4	12	4	—	—	3	—	3
24	53—00	165—00W	16.0	11.0	4	4	12	4	18	41	52	12	123
25	53—40	165—00W	13.5	10.1	4	4	11	4	—	1	10	4	15
27	56—00	165—00W	13.5	10.1	4	4	11	4	—	—	3	—	3
27*	56—00	165—00W	8.0	10.2	4	4	11	4	—	—	—	—	
28	56—00	165—00W	14.5	10.2	4	4	11	4	—	—	—	1	1
30	53—00	165—00W	16.0	11.5	4	4	11	4	1	—	17	2	20
31	53—00	165—00W	16.0	11.8	4	4	11	4	—	7	14	6	27
Aug. 9	50—00	165—00W	16.2	11.4	4	4	12	4	—	7	9	—	16
11	53—00	165—00W	13.0	11.9	4	4	12	4	—	—	2	—	2
14	54—30	166—00W	15.2	10.4	4	4	12	4	—	—	1	—	1
15	55—00	165—00W	16.5	9.5	4	4	12	4	—	1	4	—	5
18	53—00	165—00W	39.0	12.8	4	4	12	4	—	6	6	2	14
20	50—00	165—00W	16.5	12.4	4	4	12	4	—	—	5	1	6
21	50—00	165—00W	17.0	12.5	4	4	12	4	—	—	2	—	2
Sept. 8	58—00	140—00W	13.5	13.8	4	4	12	4	—	—	—	—	

* Day set.

[1] Mesh size in inches.

Chum					Pink					Coho					Chinook
2½	3¼	4½	5¼	Total	2½	3¼	4½	5¼	Total	2½	3¼	4½	5¼	Total	Total
—	2	24	8	34	—	15	83	1	99	—	—	—	—	—	—
—	3	53	6	62	—	15	103	—	118	—	—	—	—	—	—
—	3	13	5	21	—	34	217	1	252	—	—	—	—	—	—
—	—	1	—	1	—	3	64	1	68	—	—	—	—	—	5
—	—	8	2	10	—	5	71	2	78	—	—	—	—	—	5
—	2	12	—	14	—	3	59	—	62	—	—	—	—	—	1
—	2	4	8	14	—	2	53	6	61	—	—	—	—	—	1
—	—	9	8	17	—	1	153	20	174	—	—	—	—	—	2
—	—	7	2	9	—	—	9	2	11	—	—	—	—	—	1
—	—	1	—	1	—	—	—	—	—	—	—	—	—	—	—
—	—	1	—	1	—	—	2	—	2	—	—	—	—	—	—
—	—	3	3	6	—	—	9	11	20	—	—	—	—	—	—
—	—	2	3	5	—	—	8	1	9	—	—	—	—	—	—
—	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—
—	—	5	5	10	—	—	5	—	5	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	6	2	8	—	—	—	—	—	—	—	—	—	—	—
3	14	68	5	90	—	3	8	1	12	—	—	—	1	1	2
1	2	28	7	38	—	—	—	—	—	—	—	1	—	1	4
—	34	55	—	89	—	—	1	—	1	—	1	2	2	5	1
—	6	43	7	56	—	—	—	—	—	—	—	1	1	2	1
8	39	198	8	253	—	—	2	—	2	—	—	1	3	4	—
—	1	18	16	35	—	2	23	4	29	—	—	—	2	2	—
—	—	2	—	2	—	—	1	—	1	—	1	5	2	8	—
—	3	3	—	6	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	2	32	2	36	—	—	3	—	3	—	—	4	1	5	—
2	4	22	4	32	—	—	1	1	2	—	2	5	5	12	—
—	26	132	5	163	—	—	—	—	—	—	—	—	—	—	—
1	13	48	1	63	—	1	1	—	2	—	—	2	—	2	—
—	—	—	—	—	—	—	—	—	—	—	—	1	—	1	—
—	—	2	—	2	—	—	2	—	2	—	—	—	—	—	—
3	55	181	8	247	—	—	—	—	—	—	—	7	1	8	—
—	2	28	6	36	—	—	—	—	—	—	—	—	—	—	—
—	—	3	3	6	—	—	—	—	—	—	—	—	—	—	—
—	—	5	6	11	—	—	—	—	—	—	—	—	—	—	—

A-20. 1957, Paragon (U.S.)

Date		Lat.(°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of shackles of varying mesh size[1]				Sockeye				
						2½	3¼	4½	5¼	2½	3¼	4½	5¼	Total
July	21	50—00	174—59W	12.5	9.8	4	4	12	4	—	2	2	—	4
	22	50—00	174—59W	12.5	10.8	4	4	12	4	—	2	8	4	14
	24	53—00	175—00W	14.0	8.6	4	4	12	4	—	—	1	—	1
	25	53—00	174—59W	14.0	8.6	4	4	12	4	—	—	1	—	1
	27	55—59	174—59W	13.0	9.3	4	4	12	4	—	—	—	—	-
	27*	56—00	175—00W	7.5	9.2	4	4	12	4	—	—	1	—	1
	28	56—00	175—00W	13.0	9.4	4	4	12	4	—	—	1	1	2
	30	53—00	174—59W	14.0	9.2	4	4	12	4	—	—	1	—	1
	31	53—00	175—00W	15.2	9.3	4	4	12	4	—	—	—	—	
Aug.	3	53—01	175—00W	14.5	9.7	4	4	12	4	—	—	1	—	1
	6	51—30	175—03W	10.2	10.4	4	4	12	4	6	12	27	5	50
	7	50—59	175—10W	15.5	10.7	4	4	12	4	7	49	79	13	147
	8	49—59	175—00W	12.5	9.9	4	4	12	4	—	5	71	6	82
	9	50—00	175—01W	15.0	11.0	4	4	12	4	1	29	126	9	165
	12	53—00	174—59W	13.2	9.4	4	4	12	4	—	—	1	1	2
	13	54—31	175—01W	10.0	10.2	4	4	12	4	—	—	—	—	—
	14	55—59	174—58W	11.0	10.1	4	4	12	4	—	1	1	2	4
	16	53—59	174—59W	11.5	9.8	4	4	12	4	—	—	—	—	—
	17	53—00	175—00W	13.5	10.1	4	4	12	4	1	—	2	1	4
	18	53—00	175—01W	14.5	10.4	4	4	12	4	—	—	—	1	1
	20	50—00	175—01W	15.5	11.6	4	4	12	4	3	21	50	7	81
	21	50—00	175—01W	14.5	12.1	4	4	12	4	4	30	49	2	85
	22	50—59	175—01W	13.2	11.1	4	4	12	4	1	31	74	13	119
	23	51—31	175—02W	11.5	11.4	4	4	12	4	3	12	33	5	53
Sept.	8	50—02	140—00W	11.5	13.8	4	4	12	4	—	—	—	—	—
	10	50—00	135—01W	16.0	14.6	4	4	12	4	—	—	—	—	—
	12	50—00	129—57W	16.5	15.7	4	4	12	4	—	—	—	—	—

* Day set.

[1] Mesh size in inches.

Chum					Pink					Coho					Chinook
$2^1/_2$	$3^1/_4$	$4^1/_2$	$5^1/_4$	Total	$2^1/_2$	$3^1/_4$	$4^1/_2$	$5^1/_4$	Total	$2^1/_2$	$3^1/_4$	$4^1/_2$	$5^1/_4$	Total	Total
—	—	18	1	19	—	—	—	—	—	—	—	5	3	8	—
—	3	48	6	57	—	—	—	—	—	—	—	7	3	10	2
—	1	18	2	21	—	—	1	—	1	—	—	2	—	2	—
—	1	—	—	1	—	—	—	—	—	—	—	—	—	—	—
—	—	—	3	3	—	—	—	—	—	—	—	—	—	—	—
—	—	1	1	2	—	—	—	—	—	—	—	—	—	—	—
—	—	3	1	4	—	—	—	—	—	—	—	—	—	—	—
—	1	6	3	10	—	—	—	1	1	—	—	—	1	1	—
—	1	1	1	3	—	—	1	—	1	—	—	—	—	—	—
—	—	4	—	4	—	—	—	—	—	—	—	—	—	—	1
1	5	66	5	77	—	—	3	4	7	—	—	4	5	9	1
—	—	4	1	5	—	—	—	—	—	—	—	2	1	3	—
—	2	53	11	66	—	—	—	—	—	—	—	3	1	4	15
—	5	43	4	52	—	—	1	—	1	—	—	1	—	1	4
—	—	1	—	1	—	—	—	—	—	—	—	—	—	—	—
—	—	2	3	5	—	—	—	—	—	—	—	—	—	—	—
—	1	10	7	18	—	—	—	—	—	—	—	—	—	—	—
—	—	1	—	1	—	—	—	—	—	—	—	—	—	—	—
1	3	58	22	84	—	—	—	—	—	—	—	—	—	—	—
—	1	24	14	39	—	—	—	—	—	—	—	—	—	—	—
—	—	22	7	29	—	—	—	—	—	—	—	—	—	—	—
—	—	14	—	14	—	—	—	—	—	—	—	—	—	—	1
—	4	24	4	32	—	—	—	—	—	—	—	—	—	—	—
—	11	142	23	176	—	—	—	—	—	—	1	2	1	4	1
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

A-21. 1957, Pioneer (U.S.)

Date	Lat.(°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of shackles of varying mesh size[1]				Sockeye				
					2½	3¼	4½	5¼	2½	3¼	4½	5¼	Total
June 10	50—00	175—00 E	15.0	5.3	4	4	11	4	11	2	33	1	49
11	50—00	175—00 E	10.5	5.6	4	4	11	4	34	7	21	5	67
12	50—00	175—00 E	11.5	6.7	4	4	11	4	53	9	29	3	94
14	53—00	175—00 E	12.0	6.6	4	4	11	4	1	3	24	3	31
20	53—00	175—00 E	10.5	5.7	4	4	11	4	21	11	24	7	63
22	53—00	180	11.5	6.3	4	4	11	4	—	4	38	10	52
29	56—00	175—00W	7.0	7.6	4	4	11	4	1	—	5	1	7
30	56—00	175—00W	12.5	7.7	4	4	11	4	2	4	32	8	46
July 3	53—00	175—00W	13.5	7.0	4	4	11	4	2	—	—	1	3
4	53—00	175—00W	13.5	7.0	4	4	11	4	2	—	2	2	6
6	50—00	175—00W	13.5	8.2	4	4	11	4	—	—	—	2	2
7	50—00	175—00W	8.0	8.3	4	4	11	4	—	—	—	—	—
8	51—00	176—00W	10.0	8.5	4	4	11	4	1	8	34	3	46
16	56—00	175—00 E	12.5	8.8	4	4	11	4	4	1	4	—	9
19	53—00	175—00 E	13.5	8.2	4	4	11	4	—	2	2	1	5
21	50—00	175—00 E	12.5	8.9	4	4	11	4	—	—	1	—	1
22	50—00	175—00 E	13.5	9.3	4	4	11	4	—	7	3	1	11
23	52—00	175—00 E	8.5	9.0	4	4	11	4	—	—	3	1	4
24	53—00	175—00 E	12.5	9.9	4	4	11	4	—	—	2	—	2
25	54—00	175—00 E	12.5	9.7	4	4	11	4	—	—	2	—	2
26	55—00	175—00 E	14.0	9.9	4	4	11	4	—	—	2	—	2
27	56—00	175—00 E	17.5	9.9	4	4	11	4	—	1	—	1	2
27*	56—00	175—00 E	7.5	9.8	4	4	11	4	—	—	—	2	2
28	56—00	175—00 E	9.2	9.8	4	4	11	4	1	—	4	1	6
30	53—00	175—00 E	15.0	10.6	4	4	11	4	—	—	—	—	—
Aug. 8	50—00	175—00 E	12.5	9.5	4	4	11	5	—	4	32	5	41
9	50—00	175—00 E	14.5	9.8	4	4	11	5	—	1	27	2	30
11	53—00	175—00 E	14.2	8.9	4	4	11	5	5	40	16	3	64
12	53—00	175—00 E	13.2	9.5	4	4	10	5	7	45	32	3	87
13	54—30	175—00 E	9.0	10.0	4	4	10	5	—	1	5	—	6
14	56—00	175—00 E	9.5	10.6	4	4	10	5	—	13	28	3	44
17	53—00	175—00 E	14.2	10.1	4	4	11	5	6	57	48	4	115
18	53—00	175—00 E	14.2	10.0	4	4	11	5	—	40	20	1	61
19	51—30	175—00 E	11.0	9.8	4	4	11	5	5	34	137	13	189
20	50—00	175—00 E	11.5	10.2	4	4	11	5	4	12	75	5	96
23	51—30	175—00 E	13.2	9.0	4	4	11	5	2	36	78	7	123
24	53—00	175—00 E	8.5	9.9	4	4	11	5	1	5	10	—	16
Sept. 7	55—00	150—00W	8.5	12.9	4	4	11	5	—	—	2	1	3

* Day set.

[1] Mesh size in inches.

Chum					Pink					Coho					Chinook
2½	3¼	4½	5¼	Total	2½	3¼	4½	5¼	Total	2½	3¼	4½	5¼	Total	Total
—	20	79	4	103	—	32	170	—	202	—	—	—	—	—	—
—	14	25	3	42	—	15	81	2	98	—	—	—	—	—	—
—	24	73	6	103	—	24	117	9	150	—	—	—	—	—	—
—	6	17	9	34	—	47	149	12	208	—	—	—	—	—	—
1	37	11	7	56	—	81	237	3	321	—	—	—	—	—	—
4	24	27	—	55	—	128	688	12	828	—	—	—	—	—	—
—	4	48	5	57	—	10	186	21	217	—	—	—	—	—	—
1	12	40	6	59	—	1	66	4	71	—	—	—	—	—	—
37	3	1	—	41	—	—	—	—	—	—	—	—	—	—	—
33	6	1	1	41	—	—	7	—	7	—	—	—	—	—	—
36	8	37	3	84	—	—	—	1	1	—	9	—	—	9	1
55	7	48	2	112	—	—	1	—	1	—	7	—	2	9	—
62	11	72	1	146	—	—	11	1	12	—	2	—	3	5	2
33	4	2	1	40	—	—	16	—	16	—	—	—	—	—	—
214	22	69	7	312	—	—	2	—	2	—	—	—	—	—	—
47	2	1	—	50	—	—	—	—	—	1	3	—	—	4	—
40	1	2	—	43	—	—	—	—	—	2	37	—	8	47	1
20	1	24	1	46	—	1	2	—	3	—	2	—	3	5	—
178	8	5	1	192	—	—	1	—	1	—	2	—	1	3	1
43	2	10	—	55	—	—	1	—	1	—	—	—	—	—	1
22	7	11	2	42	—	—	1	1	2	—	—	—	—	—	—
91	8	21	4	124	—	—	—	—	—	—	—	—	1	1	—
4	1	2	—	7	—	—	1	—	1	—	—	—	—	—	—
11	16	31	6	64	—	—	—	—	—	1	1	—	—	2	—
15	4	16	3	38	—	—	—	1	1	—	2	—	1	3	—
—	3	21	5	29	—	—	—	—	—	—	1	—	5	6	—
—	4	24	—	28	—	—	—	—	—	—	—	—	2	2	2
1	3	35	8	47	—	—	2	—	2	—	—	—	—	—	—
1	7	77	21	106	—	—	—	2	2	—	—	—	—	—	—
2	22	23	2	49	—	—	1	—	1	—	—	—	—	—	—
8	30	17	2	57	—	—	—	—	—	—	—	—	—	—	—
5	16	86	20	127	—	—	1	1	2	—	—	—	1	1	—
—	9	56	16	81	—	—	1	—	1	—	—	—	—	—	—
—	4	48	10	62	—	—	2	—	2	1	10	—	4	15	6
—	1	13	3	17	—	—	—	—	—	—	—	—	—	—	—
—	9	128	28	165	—	—	2	—	2	—	1	—	—	1	2
—	5	40	7	52	—	—	—	—	—	—	1	—	—	1	—
—	7	16	8	31	—	—	—	—	—						

A-22. 1958, Fort Ross (Canada)

Date	Lat.(°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of shackles of varying mesh size[1]				Sockeye				
					2½	3¼	4½	5¼	2½	3¼	4½	5¼	Total
May 17	50—00	135—00W	9.5	9.6	6	6	18	6	—	—	3	—	3
19	50—00	135—00W	7.0	9.4	6	6	18	6	—	—	—	—	
24	50—00	145—00W	10.0	7.6	6	6	18	6	3	10	23	3	39
25	50—00	145—00W	8.0	7.7	5	6	18	6	1	2	34	3	40
27	50—00	145—00W	8.0	7.9	5	6	18	6	1	15	58	4	78
June 7	55—00	150—00W	8.0	8.1	5	6	18	6	—	3	56	42	101
8	55—00	150—00W	8.0	7.8	5	6	18	6	1	4	20	12	37
9	55—00	150—00W	9.0	8.2	4	6	18	6	—	1	29	4	34
10	55—00	150—00W	9.5	8.3	4	5	17	6	1	13	105	36	155
15	55—00	155—00W	8.0	7.8	4	6	18	6	5	6	72	63	146
16	55—00	155—00W	9.5	7.4	3	3	9	3	3	1	24	7	35
23	50—00	155—00W	12.0	7.6	4	4	10	4	1	10	12	2	25
24	50—00	155—00W	9.5	7.8	4	4	10	4	11	22	23	5	61
25	50—00	155—00W	11.0	8.1	4	4	10	4	6	10	10	10	36
26[2]	50—00	155—00W	11.0	8.5	—	—	1	—	—	—	1	—	1
July 26	50—00	145—00W	8.0	13.7	1	3	7	2	—	—	—	1	1
Aug. 1	50—00	155—00W	9.0	10.2	1	3	7	3	—	1	—	—	1
15	55—00	155—00W	10.0	11.0	1	3	7	3	—	—	2	1	3
18	55—00	145—00W	8.0	13.4	1	3	7	3	—	—	—	—	

[1] Mesh size in inches.

[2] Surface gillnets lost except for one shackle.

A-23. 1958, Key West II (Canada)

Date	Lat.(°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of shackles of varying mesh size[1]				Sockeye				
					2½	3¼	4½	5¼	2½	3¼	4½	5¼	Total
May 11	51—00	130—00W	12.0	10.1	6	6	18	6	1	1	—	—	2
17	50—00	135—00W	12.0	8.7	6	6	18	6	—	—	1	—	1
18	50—00	135—00W	10.0	9.4	6	6	18	6	—	—	3	2	5
19	50—00	135—00W	12.0	9.5	6	6	18	6	—	—	1	—	1
28	51—00	130—00W	11.0	11.1	6	6	18	6	—	1	1	1	3
June 1	55—00	145—00W	12.0	8.5	6	6	18	6	—	—	30	3	33
2	55—00	145—00W	14.5	8.7	6	6	16	6	1	2	18	3	24
4	58—00	145—00W	13.0	10.1	5	6	8	5	1	5	78	25	109
5	58—00	145—00W	13.5	10.2	5	6	8	5	1	4	99	32	136
13	55—00	135—00W	12.5	11.0	6	6	11	5	—	—	—	—	
14	55—00	135—00W	11.5	11.1	6	6	11	5	—	—	1	—	1
15	55—00	135—00W	10.0	11.6	6	6	11	5	8	8	11	3	30
16	55—00	135—00W	11.5	11.7	6	6	11	5	—	—	2	1	3
Aug. 16	55—00	135—00W	10.0	14.3	2	2	4	—	—	—	—	—	
23	58—00	145—00W	10.0	14.7	2	2	4	—	—	—	—	—	
24	58—00	145—00W	8.5	13.9	—	—	—	—	—	—		—	

[1] Mesh size in inches.

	Chum				Pink					Coho					Chinook				
2	3¼	4½	5¼	Total	2½	3¼	4½	5¼	Total	2½	3¼	4½	5¼	Total	2½	3¼	4½	5¼	Total
1	—	—	—	1	—	—	1	2	3	—	—	5	—	5	—		—	—	—
-	—	-	-	-	-	-	—	—	—	—	—	—	—	—		—	—	—	
-	—	14	1	15	—	2	1	—	3	—	—	2	1	3	—	—	—	1	1
-	3	20	3	26	—	2	2	—	4	—	—	2	—	2	—	—	—	—	—
-	1	37	7	45	—	6	5	—	11	—	—	—	—	—	—	—	—	—	—
-	—	21	5	26	—	—	—	—	—	—	—	—		—	—		—		—
-	—	7	1	8	—	—	1	—	1	—	—	—	—	—	—	—	—	—	—
-	—	19	6	25	—	—	1	—	1	—	—	—	—	—	—	—	—	—	—
-	—	8	4	12	—	—	5	—	5		—	—	-	-	—	—	—	—	-
-	—	9	4	13	—	—	9	—	9	—	—	—	—	—		—	—	—	—
-	—	3	—	3	—	—	1	—	1	—	—	—	—	—	—	—	—	—	—
-	—	9	4	13	—	1	8	—	9	—	—	—	—	—	—	—	—	—	—
-	4	28	9	41	—	1	1	1	3	—	—	—	—	—	—	—	2	1	3
-	1	9	4	14	—	—	11	—	11	—	—	—	—	—	—	—	—	1	1
-		—	—	—	—	—	—	—	—	—	-	—	—	—	—	-	—	—	—
				—	—	—	—			—	—			—	—	—	—	—	—
-	11	22	14	47	—	-	—	—	—	—	—	—	—	—	—	—	—	—	—
2	4	14	5	25	—	—	—	1	1	—	—	—	2	2	—	—	—	—	—
—	—	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

	Chum				Pink					Coho					Chinook				
/2	3¼	4½	5¼	Total	2½	3¼	4½	5¼	Total	2½	3¼	4½	5¼	Total	2½	3¼	4½	5¼	Total
—	—	1	—	1	1	—	1	—	2	—	—	1	—	1	—	—	—	—	—
—	—	—	—	—	—	—	1	1	2	1	—	6	2	9		—	—	—	
1	14	47	—	62	—	3	7	—	10	—	2	19	—	21	—		—		—
—	—	8	—	8	—	1	—	—	1	—	—	4	—	4	—	—	—	—	—
1	—	1	2	4	1	1	5	—	7	—	—	5	1	6	—	-	—		—
1	—	10	4	15	—	—	4	—	4	—	—	1	—	1	—		—		-
—	—	3	1	4	—	—	5	—	5	—	—	—	—	—		—		—	—
—	—	19	5	24	2	—	4	—	6	—	—	—	—	—	—	—	—	—	—
—	—	18	1	19	—	—	29	2	31	—	—	2	—	2	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	1	—	2	3	—	—	—	—	—
—	—		—		—	—			-	—	—	—	—	-	—		—		—
2	12	3	1	18	5	8	59	5	70	1	1	9	9	20		—		—	—
—	2	3	—	5	—	—	2	4	6	—	2	4	3	9		—			—
—		—	—	—	—	-	—	-		-	—	—	-		—	-	—		
—			—	—	-		—	—	—	-		-		—				—	-
—	—				—	—	—	—	—	—	-	—	-	—	—	—	-	—	

A-24. 1958, KANO-MARU (Japan). (Catches by 4 1/2″, 5 1/4″ and 4.8″ mesh gillnets were combined.)

Date	Lat.(°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of tans[1] of varying mesh size[2]					Sockeye					
					2 1/2	3 1/4	4 1/2	5 1/4	4.8	2 1/2	3 1/4	4 1/2	5 1/4	4.8	Total
May 19	46—59	156—01 E	10.0	1.7	2	2	6	2	40	—	—		2		2
21	49—02	157—53 E	10.0	1.2	2	2	6	2	40	—	—		4		4
23	51—06	159—57 E	10.0	2.9	2	2	6	2	40	—	—		—		
24	52—01	160—45 E	10.0	2.4	2	2	6	2	40	—	—		4		4
27	53—02	161—57 E	10.0	2.3	2	2	6	2	40	—	—		3		3
June 1	53—45	162—57 E	9.0	2.5	2	2	6	2	40	—	—		11		11
2	54—00	163—00 E	10.0	3.2	2	2	6	2	40	—	—		47		47
4	55—02	164—02 E	10.0	3.1	2	2	6	2	40	—	—		40		40
5	56—01	164—57 E	10.0	4.0	2	2	6	2	40	—	—		30		30
6	57—03	166—03 E	9.5	3.6	2	2	6	2	40	—	2		16		18
7	57—54	166—19 E	9.0	3.4	2	2	6	2	40	—	—		14		14
8	59—00	166—57 E	10.0	3.2	2	2	6	2	40	—	—		15		15
10	59—31	169—00 E	10.0	3.8	2	2	6	2	40	—	—		22		22
11	59—27	171—04 E	10.0	4.3	2	2	6	2	40	—	—		15		15
12	59—28	170—54 E	10.5	3.9	2	2	6	2	40	—	—		14		14
13	59—20	170—52 E	9.5	5.4	—	2	6	2	40	—	—		26		26
17	59—16	169—03 E	10.0	5.2	—	2	6	2	40	—	1		51		52
18	59—29	169—00 E	10.0	5.2	—	2	6	2	40	—	1		29		30
19	58—52	167—15 E	10.0	5.4	—	2	6	2	43	—	2		27		29
20	58—56	166—57 E	9.5	6.1	2	2	6	2	43	—	—		24		24
21	59—01	167—00 E	9.5	6.5	2	2	6	2	43	—	—		20		20
22	58—02	166—03 E	9.0	5.7	2	2	6	2	43	1	—		3		4
25	58—00	166—00 E	9.0	6.5	2	2	6	2	43	—	—		10		10
26	58—00	166—00 E	7.0	6.4	2	2	6	2	43	—	—		10		10
30	56—01	164—58 E	9.5	6.3	2	2	6	2	43	—	—		10		10
July 19	46—56	154—55 E	9.5	7.8	2	2	6	2	45	—	—		—		
20	47—33	156—35 E	10.5	9.1	2	2	6	2	45	7	9		—		16
29	55—00	164—00 E	9.5	8.3	2	2	6	2	45	22	14		140		176
31	59—18	170—38 E	10.0	9.5	2	2	6	2	45	—	11		163		174
Aug. 2	59—25	169—04 E	9.0	10.5	2	2	6	2	45	—	24		90		114
3	58—51	167—04 E	9.5	9.1	2	2	6	2	45	22	22		110		154
5	58—00	166—00 E	9.5	10.7	2	2	6	2	45	2	6		137		145
6	58—00	168—26 E	9.5	10.3	2	2	6	2	45	1	14		85		100
8	58—03	171—00 E	9.5	9.3	2	2	6	2	45	3	11		99		113
9	57—00	171—00 E	10.0	8.9	2	2	6	2	45	—	8		126		134
10	57—02	168—25 E	8.0	8.9	2	2	6	2	45	5	24		82		111
11	56—58	166—00 E	10.0	10.5	2	2	6	2	45	—	—		111		111
12	56—06	166—00 E	10.0	10.1	2	2	6	2	45	—	3		3		6
13	55—56	168—36 E	10.0	10.1	2	2	6	2	45	—	4		40		44
14	56—00	170—55 E	10.0	9.6	2	2	6	2	45	1	5		134		140
15	55—01	170—58 E	8.5	9.5	2	2	6	2	45	—	3		42		45
16	55—02	169—25 E	10.5	9.4	2	2	6	2	45	—	—		22		22

[1] Length of one tan is 180 feet.

[2] Mesh size in inches.

Chum					Pink					Coho					Chinook				
2	$3^1/_4$	$4^1/_2$	$5^1/_4$	4.8 Total	$2^1/_2$	$3^1/_4$	$4^1/_2$	$5^1/_4$	4.8 Total	$2^1/_2$	$3^1/_4$	$4^1/_2$	$5^1/_4$	4.8 Total	$2^1/_2$	$3^1/_4$	$4^1/_2$	$5^1/_4$	4.8 Total
–	—		43	43	—	—		—	—	—	—		—	—	—	—		—	—
–	—		115	115	—	—		—	—	—	—		—	—	—	—		—	—
	—		64	64	—	—		—	—	—	—		—	—	—	—		1	1
–	–		51	51	—	—		2	2	—	—		—	—	—	—		1	1
	–		19	19	—	—		1	1		–		-		–			-	—
–	—		13	13	–	-		—	—	—					–	-			—
–	—		42	42	—	—		8	8	—			–	–	–	–		-	
-	-		35	35	—	—		5	5	—	—		—	—	—	—		—	—
	—		4	4	—	—		15	15	—	—		—	—	—	—		1	1
–	–		12	12	—	—		9	9	—	—		—	—	—	—		1	1
–	—		16	16	—	1		9	10	—	—		—	—	—	—		1	1
			5	5	—	—		1	1		–		--	–	–	--			—
-			4	4	—	—		16	16	—	—		—	—	—	—		2	2
			4	4	—	—		5	5	—	—		—	—	—	—		1	1
–	–		1	1	—	—		3	3	—	—		—	—	—	—		1	1
–	—		11	11	—	—		11	11	—	—		—	—	—	—		1	1
	-		14	14	—	6		88	94	—	—		—	—				—	
–	–		8	8	—	2		48	50	—	—		—	–	–	—		–	–
–	–		23	23	—	—		61	61	—	—		—	—	—	—		—	—
-			20	20	—	3		90	93	—	—		—	—	—	—		3	3
–	—		28	28	1	2		159	162	—	—		—	—	1	—		2	3
–	1		52	53	—	—		68	68		–		–	–	–			–	
–			15	15	—	1		183	184	—	—		—	—	—	1		2	3
-			13	13	—	—		396	396	—	—		—	—	—	—		—	—
—	—		29	29	—	—		55	55	—	—		—	—	—	—		1	1
—	1		27	28	1	2		157	160	—	—		7	7	—	—		—	—
1	—		10	11	1	—		239	240	—	—		7	7	—	—		—	—
3	4		13	20	—	2		—	2	—	—		6	6	—	—		—	—
7	44		120	171	—	—		1	1	—	—		—	—	—	—		3	3
—	15		146	161	—	—		—	—	—	—		—	—	—	—		—	—
—	34		50	84	—	—		2	2	—	—		1	1	—	—		—	—
12	18		34	64	—	—		2	2	—	—		4	4	—	—		1	1
5	13		24	42	—	—		1	1	—	—		2	2	—	—		—	—
6	36		29	71	—	—		1	1	—	—		3	3	—	—		—	—
8	11		15	34	—	—		—	—	—	—		—	—	—	—		—	—
	17		28	45	—	—				—					–	–		–	–
3	5		15	23	-					–					–	-		–	–
—	1		4	5	—	—		—	—	—	—		1	1	–			–	–
3	12		29	44	—	—		1	1	—	—		2	2	—			–	–
13	18		42	73	—	—		1	1	—	—		1	1	—	—		1	1
1	4		30	35	—	—		—	—	—	—		—	—	—	—		—	—
—	3		18	21	—	—		—	—	—	—		—	—	—	—		—	—

A-25. 1958, WAKASHIO-MARU (Japan). (Catches by 4 1/2", 5 1/4" and 4.8" mesh gillnets were combined.)

Date	Lat. (°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of tans[1] of varying mesh size[2]					Sockeye					
					2½	3¼	4½	5¼	4.8	2½	3¼	4½	5¼	4.8	Total
May 20	50—31	179—45W	11.0	5.1	2	2	4	4	40	—	—		1		1
24	50—19	177—34W	11.5	4.9	2	2	12	4	40	—	—		37		37
27	50—30	175—00W	11.5	5.3	2	2	12	4	40	—	—		25		25
28	50—30	172—30W	11.0	5.7	2	2	12	4	40	—	—		27		27
30	50—30	170—00W	11.0	5.2	2	2	12	4	38	1	—		2		3
June 1	53—03	172—00W	11.5	4.7	2	2	12	4	38	1	—		23		24
2	53—02	172—32W	11.5	4.6	2	2	12	4	38	6	1		21		28
3	53—00	175—00W	11.5	5.1	2	2	12	4	38	1	1		31		33
4	53—00	175—00W	11.5	5.6	2	2	12	4	38	—	—		31		31
8	53—00	177—30W	12.0	5.1	2	2	12	4	36	3	1		78		82
9	53—00	180	11.0	4.6	2	2	12	4	36	—	—		17		17
10	52—54	179—40W	11.0	4.6	2	2	12	4	36	—	—		22		22
11	53—00	177—30 E	10.5	5.0	2	2	12	4	36	—	—		9		9
12	52—57	177—38 E	11.0	4.9	2	2	12	4	36	—	—		12		12
13	53—00	175—00 E	11.5	5.0	2	2	12	4	36	—	—		9		9
14	53—02	174—56 E	11.0	5.2	2	2	12	4	36	—	—		11		11
15	54—00	172—30 E	11.0	5.4	2	2	12	4	36	1	—		15		16
18	56—00	172—30W	11.0	6.5	2	2	12	4	36	2	2		79		83
19	56—00	172—50W	10.0	6.9	2	2	12	4	36	—	1		38		39
22	56—08	175—00W	10.5	5.9	2	2	12	4	36	4	1		33		38
23	56—03	177—26W	10.5	5.1	2	2	12	4	36	—	2		17		19
24	55—55	179—57W	10.0	4.9	2	2	12	4	35	—	1		13		14
25	55—56	179—58W	10.0	5.1	2	2	12	4	35	—	—		9		9
26	56—00	177—30 E	10.0	6.9	2	2	12	4	35	—	—		7		7
27	56—00	175—00 E	10.0	6.5	2	2	12	4	35	1	—		9		10
29	56—02	174—10 E	10.5	5.8	2	2	12	4	35	1	—		11		12
July 1	56—00	172—30 E	10.0	6.3	2	2	12	4	35	—	—		8		8
2	56—00	172—30 E	10.0	6.3	2	2	12	4	35	—	—		11		11
19	46—30	156—00 E	11.5	8.4	4	4	12	4	40	—	—		—		—
20	47—30	156—30 E	8.5	8.8	4	4	12	4	40	—	—		—		—
25	52—28	168—58 E	9.5	8.6	4	4	12	4	40	—	21		126		147
29	52—03	170—35 E	10.0	8.4	4	4	12	4	40	6	12		92		110
30	53—08	171—44 E	9.5	8.0	2	2	12	4	40	3	3		98		104
31	54—00	171—00 E	10.5	8.2	2	2	12	4	40	—	1		22		23
Aug. 1	54—00	169—00 E	10.0	7.9	2	2	12	4	40	1	12		106		119
2	53—05	169—00 E	10.0	8.1	2	2	12	4	40	—	4		166		170
5	54—05	166—55 E	10.0	9.1	2	2	12	4	40	—	10		99		109
6	54—00	165—00 E	11.0	9.4	2	2	12	4	40	1	10		235		246
7	55—00	164—00 E	10.5	9.4	2	2	12	4	40	1	3		95		99
8	55—03	164—05 E	10.0	10.0	2	2	12	4	40	10	18		261		289
9	54—00	163—00 E	10.5	10.0	2	2	12	4	40	4	16		181		201
10	53—00	161—25 E	10.5	10.4	2	2	12	4	40	1	5		59		65
11	53—00	164—30 E	11.0	9.7	2	2	12	4	40	—	—		60		60
13	53—00	167—10 E	11.0	10.1	2	2	12	4	40	—	3		172		175
14	52—00	166—00 E	11.0	9.6	2	2	12	4	40	—	1		85		86
15	52—00	163—30 E	11.0	10.2	2	2	12	4	40	—	1		54		55
17	51—55	161—05 E	11.0	10.8	2	2	12	4	40	1	10		100		111
18	51—56	159—50 E	11.0	11.9	2	2	12	4	40	1	6		49		56

[1] Length of one tan is 180 feet.

[2] Mesh size in inches.

Chum						Pink						Coho						Chinook					
2½	3½	4½	5½	4.8	Total	2½	3½	4½	5½	4.8	Total	2½	3½	4½	5½	4.8	Total	2½	3½	4½	5½	4.8	Total
—	—		42		42	—	—		8		8	—	—		—				—				
—	—		63		63	—	3		17		20	—	—		—		—	—	—		1		1
—	—		10		10	—	3		22		25	—	—						—		—		
—	—		35		35	—	—		21		21	—	—		—				—		—		—
—	—		19		19	—	—		1		1	—	—		—				—				—
—	—		45		45	—	1		15		16		—				—						
—	—		48		48	—	—		27		27	—	—		—		—	—	—		4		4
—	—		1		1	—	—		1		1	—	—		—		—	—	—		1		1
—	—		8		8	—	—		5		5	—	—		—		—	—	3		1		4
—	—		4		4	—	—		7		7	—	—		—		—	—	—		1		1
—	—		8		8	—	—		11		11	—	—		—				—		—		
—	—		20		20	—	—		9		9	—					—		—				
—	—		19		19	—	1		8		9	—	—		—			—					
—	—		10		10	—	—		2		2						—						
—	1		32		33	—	—		8		8	—	—		—			—	—		—		
—	3		166		169	—	1		4		5	—	—		—		—	—	—		1		1
—	—		96		96	—	1		10		11	—			—				—				
1	—		22		23	—	—		18		18	—	—		—		—	—	4		—		4
—	—		17		17	—	1		21		22	—	—		—		—	4	4		16		24
—	—		11		11	—	—		4		4	—	—		—		—	—	2		18		20
—	17		98		115	—	—		9		9	—	—				—						
—	2		44		46	—	—		7		7	—	—		—		—	—	—		6		6
—	7		86		93	—	—		6		6	—	—		—		—	—	—		2		2
—	3		122		125	—	—		6		6	—	—		—		—	—	—		2		2
—	2		80		82	—	—		14		14	—	—		—		—	—	—		1		1
—	16		330		346	—	—		4		4	—	—		—		—	—	—		6		6
—	1		24		25	—	—		1		1	—	—		—		—	—	—		2		2
—	1		64		65	—	—		11		11	—											
—	—		20		20	2	26		430		458	—	2		8		10	—	—		—		—
—	—		7		7	1	11		126		138	—	4		8		12	—	—		—		—
9	33		54		96	—	—		1		1	—	2		21		23	—	1		—		1
5	11		55		71	—	—		1		1	—	3		72		75	—	—		1		1
—	—		30		30	—	—		—		—	—	—		5		5	—	—		—		
—	2		127		129	—	—		3		3	—	—		6		6	—	—		—		—
—	1		68		69	—	—		—		—	—	—		2		2	—	—		—		—
—	2		55		57	—	—		1		1	—	—		18		18	—	—		—		—
—	4		37		41	—	—		1		1	—	—		11		11	—	—		—		—
—	3		61		64	—	—		2		2	—	—		40		40	—	—		1		1
—	—		21		21	—	—		—		—	1	—		29		30	—	—		—		—
3	19		57		79	—	—		1		1	—	—		6		6	—	—		2		2
2	13		96		111	—	—		5		5	—	—		56		56						
—	7		55		62	—	—		1		1	—	2		28		30	—	—		—		—
—	1		71		72	—	—		—		—	—	—		16		16						
—	2		21		23	—	—		—		—	—	1		27		28	—	—				
—	1		44		45	—	—		1		1	—	—		8		8	—	—		—		—
—	2		42		44	—	—		—		—	—	1		12		13	—	—		2		2
—	—		24		24	—	—		1		1	—	2		20		22	—	—		—		—
—	—		17		17	—	—		1		1	—	1		39		40	—	—		—		—

A-26. 1958, Attu (U.S.)

Date	Lat.(°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of shackles of varying mesh size[1]				Sockeye				
					$2^1/_2$	$3^1/_4$	$4^1/_2$	$5^1/_4$	$2^1/_2$	$3^1/_4$	$4^1/_2$	$5^1/_4$	Total
May 28	51—00	180	12.2	5.1	4	4	12	4	1	1	6	3	11
29	50—03	180	12.7	5.2	4	4	12	4	—	—	9	—	9
31	49—00	180	35.5	4.8	4	4	12	4	—	1	5	1	7
June 1	48—33	178—29 E	13.5	4.7	4	4	12	4	—	—	3	—	3
8	53—07	175—02 E	13.5	4.7	4	4	12	4	—	2	6	3	11
10	54—00	178—00W	15.2	5.3	4	4	12	4	—	—	8	3	11
17	53—30	170—02W	12.7	6.3	4	4	12	4	1	3	28	19	51
18	53—59	167—32W	12.0	6.9	4	4	12	4	—	—	—	—	—
24	54—59	167—22W	13.0	6.7	4	4	12	4	—	—	2	—	2
25	55—04	169—24W	14.5	6.6	4	4	12	4	1	7	49	27	84
26	55—58	170—04W	14.5	6.8	4	4	12	4	—	2	16	7	25
27	56—57	169—58W	16.5	6.8	4	4	12	4	—	—	3	1	4
28	57—59	169—59W	14.5	6.5	4	4	12	4	—	—	1	1	2
30	55—04	174—52W	13.5	6.3	4	4	12	4	—	1	—	1	2
July 1	53—58	175—00W	14.7	6.7	4	4	12	4	—	—	—	—	—
2	53—01	175—00W	14.0	6.8	4	4	12	4	—	—	5	2	7
11	52—25	177—02W	17.0	6.7	4	4	12	4	—	—	1	—	1
12	52—04	178—38W	13.5	7.2	4	4	12	4	1	5	8	—	14
13	52—31	179—59W	13.7	6.4	4	4	12	4	—	—	2	—	2
14	53—31	180	12.2	6.5	4	4	12	4	3	15	9	—	27
15	54—00	178—00 E	13.2	7.3	4	4	12	4	1	12	3	1	17
16	54—02	176—28 E	15.0	8.0	4	4	12	4	—	—	1	—	1
17	54—00	175—00 E	15.0	8.9	4	4	12	4	—	3	2	1	6
18	55—00	175—00 E	14.2	8.5	4	4	12	4	1	10	6	—	17
19	55—59	175—01 E	13.7	8.5	4	4	12	4	—	4	1	—	5
20	55—01	174—58 E	14.0	8.8	4	4	12	4	—	2	—	—	2
21	54—00	174—58 E	14.0	9.1	4	4	12	4	1	—	2	—	3
22	53—21	174—04 E	15.0	8.2	4	4	12	4	—	1	—	1	2
Aug. 5	53—00	174—59W	12.0	8.8	4	4	12	4	—	4	4	—	8
6	54—00	175—00W	15.0	9.0	4	4	12	4	—	—	—	—	—
7	55—00	175—00W	15.0	9.0	4	4	12	4	—	6	7	1	14
10	52—00	172—30W	23.7	6.6	4	4	12	4	—	—	—	—	—
17	52—00	165—00W	15.0	13.6	4	4	12	4	—	9	29	4	42
18	51—00	165—00W	14.0	10.2	4	4	12	4	—	9	18	4	31
19	50—00	165—00W	13.7	9.8	4	4	11	4	2	1	30	1	34
25	52—35	145—03W	13.0	11.8	4	4	11	3	—	—	—	—	—
27	55—00	140—00W	14.5	14.1	4	4	11	3	—	—	—	—	—

[1] Mesh size in inches.

Chum					Pink					Coho					Chinook
2½	3¼	4½	5¼	Total	2½	3¼	4½	5¼	Total	2½	3¼	4½	5¼	Total	Total
—	2	4	1	7	—	—	2	—	2	—	—	—	—	—	—
—	—	35	2	37	—	—	2	—	2	—	—	—	—	—	—
—	—	41	4	45	—	7	2	—	9	—	—	—	—	—	—
—	—	13	5	18	—	—	—	—	—	—	—	—	—	—	—
—	—	18	12	30	—	1	17	—	18	—	—	—		—	—
—	—	3	1	4	—	—	4	1	5	—	—	—	—	—	—
—	—	26	11	37	—	1	27	2	30	—	—	—	—	—	2
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	5	—	5	—	—	—	—	—	—	—	—	—	—	—
—	2	10	4	16	—	—	5	—	5	—	—	—	—	—	—
—	—	21	5	26	—	—	5	—	5	—	—	—	—	—	1
—	—	1	—	1	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	2	1	3	—	—	—	—	—	—	—	—	—	—	1
—	—	4	—	4	—	—	4	—	4	—	—	—	—	—	—
—	1	1	—	2	—	—	—	—	—	—	—	—	—	—	1
—	4	8	1	13	—	—	—	—	—	—	—	—	—	—	—
4	6	7	—	17	—	—	—	—	—	—	—	—	—	—	—
38	7	12	2	59	—	—	—	—	—	—	—	—	—	—	—
207	74	42	3	326	—	—	3	—	3	—	—	—	—	—	
24	11	16	1	52	—	1	1	—	2	—	—	—	—	—	—
83	13	15	2	113	—	—	—	—	—	—	—	—	—	—	—
132	43	9	2	186	—	—	—	—	—	—	—	—	—	—	—
87	51	10	3	151	—	—	—	—	—	—	—	—	—	—	1
102	20	3	—	125	—	—	—	—	—	—	—	—	—	—	—
45	16	12	3	76	—	—	—	—	—	—	—	1	—	1	1
15	31	16	3	65	—	—	2	—	2	1	—	1	—	2	—
1	7	18	2	28	—	—	—	—	—	—	—	—	—	—	
—	18	46	5	69	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	2	13	1	16	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	12	42	11	65	—	—	—	—	—	—	—	—	—	—	—
—	1	8	8	17	—	—	—	—	—	—	—	—	—	—	1
—	5	15	1	21	—	—	—	—	—	—	—	—			—
—	—	1	1	2	—	—	—	—	—	—	—	—			—
—	—	—	—		—	—	—	—	—	—	—	—	1	1	

A-27. 1958, Pioneer U.S.

Date		Lat.(°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of shackles of varying mesh size[1]				Sockeye				
						2½	3¼	4½	5¼	2½	3¼	4½	5¼	Total
May	28	53—00	180	12.0	3.3	4	4	12	4	—	—	5	1	6
	29	53—00	178—15 E	12.2	3.2	4	4	12	4	—	—	4	2	6
	31	55—00	174—00 E	12.0	2.7	4	4	12	4	—	1	2	2	5
June	1	54—00	173—00 E	12.5	3.6	4	4	12	4	—	—	11	7	18
	2	53—00	172—00 E	10.2	3.6	4	4	12	4	—	—	5	7	12
	8	51—35	173—00 E	12.5	4.6	4	4	12	4	—	1	8	3	12
	17	53—00	180	13.2	5.1	4	4	12	4	—	—	3	1	4
	18	54—00	180	13.5	6.3	4	4	12	4	—	—	6	6	12
	22	54—43	178—14 E	89.2	4.6	4	4	12	4	1	—	3	6	10
	30	50—00	180	14.0	5.9	4	4	12	4	11	29	4	—	44
July	6	51—17	175—53W	11.7	7.0	4	4	12	4	8	12	14	5	39
	7	50—30	175—00W	13.0	7.1	4	4	12	4	1	6	8	3	18
	8	49—30	175—00W	13.0	6.6	4	4	12	4	—	5	—	1	6
	10	50—22	177—45W	15.2	6.9	4	4	12	4	—	—	6	—	6
	12	50—59	178—50 E	13.0	6.8	4	4	12	4	9	28	8	5	50
	13	50—18	177—28 E	12.5	6.7	4	4	12	4	—	5	6	—	11
	14	49—39	176—11 E	13.2	7.1	4	4	12	4	—	1	3	—	4
	15	49—00	175—00 E	12.0	7.2	4	4	12	4	—	2	12	—	14
	16	50—00	175—00 E	12.7	7.1	4	4	12	4	—	6	10	1	17
	17	51—00	175—00 E	12.0	7.2	4	4	12	4	—	1	4	2	7
	18	52—00	175—00 E	13.2	7.2	4	4	12	4	7	31	12	4	54
	19	53—00	175—00 E	12.7	8.6	4	4	12	4	1	1	—	—	2
	20	53—15	175—45 E	12.0	8.2	4	4	12	4	—	—	—	—	—
	21	53—07	176—55 E	12.7	8.0	4	4	12	4	1	2	1	—	4
	22	53—00	178—00 E	14.7	8.1	4	4	12	4	—	1	—	—	1
	24	53—00	179—48 E	14.7	7.2	4	4	12	4	—	—	—	—	—
	25	53—00	178—30W	13.2	7.1	4	4	12	4	—	—	—	—	—
	26	53—00	176—54W	12.5	7.4	4	4	12	4	—	—	—	—	—
	27	52—58	175—13W	12.7	7.9	4	4	12	4	1	—	2	4	7
	28	52—22	176—17W	13.0	7.7	4	4	12	4	—	—	—	—	—
Aug.	5	51—30	175—00W	9.5	8.5	4	4	12	4	6	36	28	3	73
	6	50—00	175—00W	11.0	8.6	4	4	12	4	4	48	36	—	88
	7	49—00	175—00W	13.5	9.1	4	4	12	4	—	15	19	3	37
	9	49—00	170—00W	15.5	9.2	4	4	12	4	—	—	9	3	12
	10	50—00	170—00W	13.0	9.3	4	4	12	4	—	6	33	—	39
	11	51—00	170—00W	12.5	9.2	4	4	12	4	3	27	36	8	74
	15	52—51	166—00W	36.2	10.0	4	4	12	4	4	9	17	8	38
	19	54—07	160—00W	13.0	10.8	4	4	12	4	—	—	—	—	—
	20	53—30	160—00W	13.2	11.1	4	4	12	4	—	—	4	1	5
	25	49—43	146—10W	12.2	11.8	4	4	12	4	—	—	—	—	—
	27	51—30	140—00W	11.5	14.9	4	4	12	4	—	—	—	—	—

[1] Mesh size in inches.

Chum					Pink					Coho					Chinook
2½	3¼	4½	5¼	Total	2½	3¼	4½	5¼	Total	2½	3¼	4½	5¼	Total	Total
—	1	—	1	2	—	—	7	2	9	—	—	—	—	—	—
—	—	—	—	—	—	—	1	—	1	—	—	—	—	—	—
—	—	3	—	3	—	—	1	1	2	—	—	—	—	—	—
—	—	1	3	4	1	—	—	—	1	—	—	—	—	—	5
—	—	21	7	28	—	—	—	1	1	—	—	—	—	—	—
—	1	33	12	46	—	1	27	1	29	—	—	—	—	—	1
—	6	50	10	66	—	—	5	2	7	—	—	1	—	1	1
—	2	40	11	53	—	—	12	1	13	—	—	—	—	—	1
—	3	49	20	72	—	—	5	—	5	—	—	—	—	—	1
70	24	6	2	102	—	—	—	—	—	—	—	1	1	2	—
16	26	6	—	48	—	—	3	—	3	—	—	—	—	—	
24	125	18	2	169	—	1	7	—	8	—	—	1	—	1	—
1	11	1	—	13	—	—	5	—	5	—	—	—	1	1	—
45	7	11	3	66	—	—	1	—	1	—	—	2	3	5	—
28	4	3	1	36	—	—	1	—	1	—	—	1	1	2	—
6	6	7	—	19	—	—	1	—	1	—	—	2	3	5	—
3	3	3	3	12	—	—	1	1	2	—	1	33	11	45	—
11	4	2	—	17	—	—	2	—	2	—	—	7	4	11	—
14	12	2	2	30	—	—	—	—	—	—	—	5	2	7	—
1	1	11	5	18	—	—	—	—	—	—	1	12	2	15	—
4	13	12	2	31	—	—	—	1	1	—	1	4	1	6	—
99	26	13	1	139	—	—	—	—	—	—	—	1	2	3	—
18	8	13	4	43	—	1	—	—	1	—	—	4	—	4	—
78	51	33	—	162	—	—	2	—	2	—	—	4	2	6	—
2	1	8	1	12	—	—	—	—	—	—	—	—	—	—	
30	36	59	4	129	—	1	1	—	2	—	—	1	—	1	—
33	66	49	5	153	—	—	5	—	5	—	—	—	7	7	—
—	—	3	—	3	—	—	—	—	—	—	—	—	—	—	—
1	20	57	4	82	—	—	2	—	2	—	—	2	2	4	1
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	2	13	2	17	—	—	—	—	—	—	3	7	6	16	1
—	2	30	5	37	—	—	—	—	—	—	—	2	3	5	3
—	8	30	6	44	—	—	—	1	1	—	—	3	1	4	—
—	2	36	9	47	—	—	—	—	—	—	—	—	1	1	—
—	7	67	10	84	—	—	—	—	—	—	—	—	—	—	1
1	25	25	1	52	—	—	—	—	—	—	—	—	—	—	1
—	77	242	46	365	—	—	2	—	2	4	2	7	2	15	1
—	—	5	1	6	—	—	—	—	—	—	—	2	—	2	—
—	9	25	2	36	—	—	—	—	—	—	—	—	1	1	1
—	—	—	—	—	—	—	—	—	—	—	—	1	—	1	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

A-28. 1959, Fort Ross Canada

Date	Lat.(°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of shackles of varying mesh size[1]				Sockeye				
					2½	3¼	4½	5¼	2½	3¼	4½	5¼	Total
May 17	55—00	141—00W	8.5	6.5	1	1	3	1	—	—	4	2	6
17*	55—00	141—00W	7.0	6.4	1	1	3	1	1	—	1	—	2
18	55—00	141—00W	8.0	6.8	1	1	3	1	4	—	12	1	17
18*	55—00	141—00W	7.0	6.4	1	1	3	1	—	—	2	3	5
19	55—00	141—00W	9.0	6.6	1	1	3	1	—	2	12	1	15
19*	55—00	141—00W	6.0	6.8	1	1	3	1	—	—	2	—	2
20	55—00	141—00W	10.0	6.8	1	1	3	1	—	—	—	1	1
20*	55—00	141—00W	6.0	7.0	1	1	3	1	—	—	4	2	6
21	55—00	141—00W	8.0	7.0	1	1	3	1	1	—	19	2	22
26	55—00	150—00W	8.5	6.8	1	1	3	1	—	—	4	3	7
26*	55—00	150—00W	8.0	6.5	1	1	3	1	—	—	1	1	2
27	55—00	150—00W	13.5	7.5	1	1	3	1	—	—	3	4	7
28	55—00	150—00W	8.0	7.1	1	1	2	1	—	—	7	—	7
28*	55—00	150—00W	6.0	7.2	1	1	2	1	—	—	—	—	—
June 10	55—39	150—23W	9.0	8.7	1	1	2	1	—	1	9	3	13
11	55—39	150—23W	9.0	9.4	1	1	2	1	—	—	4	2	6
12	55—39	150—23W	7.0	9.9	1	1	2	1	—	2	5	1	8
July 5	50—00	135—00W	8.0	11.3	2	1	1	2	—	—	—	—	—
6	50—00	135—00W	8.5	12.1	2	1	1	2	—	—	2	—	2
7	50—00	135—00W	9.0	12.2	2	1	1	2	—	—	—	3	3
10	50—00	135—00W	9.0	11.8	1	1	3	1	—	—	4	1	5
11	50—00	135—00W	9.5	12.0	1	1	3	1	—	—	11	—	11
15	52—30	142—00W	8.0	10.5	1	1	3	1	—	—	1	5	6
18	52—30	142—00W	8.0	11.0	1	1	3	1	—	—	1	2	3
19	52—30	142—00W	8.5	11.0	1	1	3	1	—	—	5	4	9
20	52—30	142—00W	8.5	11.2	1	1	3	1	—	—	1	—	1
21	52—30	142—00W	8.5	11.1	1	1	3	1	—	1	—	1	2
25	54—10	150—30W	8.0	11.0	1	1	3	1	—	6	3	1	10
26	54—10	150—30W	8.0	10.9	1	1	3	1	1	2	6	2	11
Aug. 1	54—30	150—37W	8.0	11.2	1	1	3	1	—	—	2	1	3
7	53—30	138—53W	8.0	11.8	3	4	10	6	—	—	6	4	10

* Day set. [1] Mesh size in inches.

A-29. 1959, Key West II (Canada)

Date	Lat.(°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of shackles of varying mesh size[1]				Sockeye				
					2½	3¼	4½	5¼	2½	3¼	4½	5¼	Total
May 18	50—00	145—00W	12.5	8.0	6	6	18	6	5	4	36	1	46
19	50—00	145—00W	11.0	7.9	6	6	18	6	2	9	44	3	58
21	55—00	145—00W	9.0	7.0	6	6	18	6	2	—	123	5	130
22	55—00	145—00W	11.5	6.5	6	6	18	6	4	—	21	1	26
23	55—00	145—00W	13.0	6.8	6	6	18	6	11	—	—	—	11
25	58—00	145—00W	11.5	7.9	6	6	18	6	3	—	175	12	190
26	58—00	145—00W	11.0	8.6	6	6	18	6	—	—	13	—	13
June 10	54—56	155—00W	12.5	8.2	6	6	18	6	18	3	70	14	105
12	55—00	155—00W	9.0	8.8	6	6	18	6	35	12	249	62	358
14	53—00	160—00W	11.5	8.0	6	6	18	6	2	1	7	4	14
24	53—00	160—00W	13.5	9.5	6	6	17	6	5	6	29	1	41
25	53—00	160—00W	14.0	9.7	6	6	17	6	37	—	56	11	104
27	50—00	160—00W	13.5	9.8	6	6	17	6	47	6	34	4	91
28	50—00	160—00W	19.5	9.6	6	6	17	6	65	8	23	4	100
29	50—00	155—00W	6.5	10.4	6	6	17	6	186	17	14	—	217
July 17	51—00	130—15W	13.0	13.9	6	6	17	6	—	—	11	—	11
18	51—00	132—00W	13.5	13.5	6	6	17	6	—	—	4	—	4
19	52—10	131—24W	10.5	13.4	6	6	17	6	—	—	8	—	8
24	52—00	134—00W	8.0	13.2	6	6	17	6	—	—	3	—	3
25	51—00	132—00W	13.0	13.3	6	6	17	6	—	—	40	—	40

[1] Mesh size in inches.

Chum					Pink					Coho					Chinook				
2 1/2	3 1/4	4 1/2	5 1/4	Total	2 1/2	3 1/4	4 1/2	5 1/4	Total	2 1/2	3 1/4	4 1/2	5 1/4	Total	2 1/2	3 1/4	4 1/2	5 1/4	Total
—	—	1	2	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—					
—	—	—	—	—	—	—	—	—		—	—	—	—	—	—	—			
—		—	—	—	—	—	—	—	—	—	—	—	—	—	—		—		
—		—	—	—	—	—	1	—	1	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—			—			—			—
—	—	—	2	2	—	—	—	—	—	—	—	—	—	—	—		—		
—	1	—	2	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	1	18	2	21		—	—	—	—	—	—	—	—	—		—	—	—	—
—	—	—	1	1	—	—	—	1	1	—	—	—	—	—	—	—	—	—	—
—	—	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—			
—	—	2	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	3	1	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	1	—	3	—	4	—	—	1	—	1	—	—	—	—	—
—	—	—	—	—	—	—	—	1	1	—	—	—	—	—	—	—	—	—	—
				—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—		—	—	—	—	—	—	—	—	—				
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		—	—
—	—	—	—	—	—	—	—	1	1	—	—	1	—	1		—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—				
—	4	3	—	7	—	—	6	—	6	—	—	—	—	—		—	—	—	—
—	1	—	—	1	—	—	2	—	2	—	—	—	—	—	—			—	—
—	—	2	—	2	—	1	2	—	3	—	—	—	—	—	—	—	—	—	
—	—	6	—	6	—	—	1	—	1	—	—	—	—	—					—
—	3	2	—	5	—	—	2	1	3	—	—	—	—	—	—	—			
—	—	1	1	2	—	—	3	—	3	—	—		—	—			—	—	
—	—	25	2	27	—		2	1	3	—		—	—		—	—	—		—
—	—	1	—	1	—	—	1	—	1		—			—			—	—	
—	—	—	1	1	—	—	—	—	—	—	—		—		—	—			

Chum					Pink					Coho					Chinook				
2 1/2	3 1/4	4 1/2	5 1/4	Total	2 1/2	3 1/4	4 1/2	5 1/4	Total	2 1/2	3 1/4	4 1/2	5 1/4	Total	2 1/2	3 1/4	4 1/2	5 1/4	Total
—	—	18	1	19	—	—	9	—	9	—	—	—	—	—	—				
—	2	4	—	6	—	3	25	1	29	—	—	8	—	8					
—	—	28	2	30	—	—	7	—	7	—	—	—	—	—		—			
—	1	4	1	6	—	—	—	—	—	—	—	—	—	—					
—	—	9	—	9	—	—	2	—	2			—		—		—			
2	—	21	4	27	—	—	—	—	—	—	—	—	—					—	—
	—	3		3			—	—	—	—	—	—	—	—					
—	—	24	3	27	—	—	5	—	5	—	—	—	—	—	—	—	—	—	—
1	2	104	60	167	—	—	12	2	14	—	—								
—	—	15	12	27	—	—	64	12	76	—	—	—	—	—	—	—	—	—	—
—	1	10	—	11	—	3	43	—	46	—	—	—	—	—	—	—	—	—	—
3	—	48	9	60	—	—	136	12	148	—	—	—							
2	25	200	12	239	1	4	43	6	54	—	—	—	—						
—	—	—	—	—	5	11	67	6	89	—	—				—				
2	4	132	—	138	—	—	16	—	16	—	—	3	—	3					
	—						—	—											
					—	—	—	—		—	—	—	—	—					
—	—	—	—	—	—	—	16	—	16	—	—	—	—	—	—	—	—		
—	—	—	1	1	—	2	—	—	2		—	—							

A-30. 1959, KANO-MARU (Japan)

Date		Lat. N	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of tans[1] of varying mesh size[2]					Sockeye					
						2 1/2	3 1/4	4 1/2	5 1/4	4.8	2 1/2	3 1/4	4 1/2	5 1/4	4.8	Total
May	25	50 30	180	10.5	4.7	4	4	4	4	50	—	1	2	5	24	32
	26	50 30	178—00W	9.0	4.9	4	4	4	4	50	1	2	12	8	42	65
	27	50 30	176—00W	10.0	5.7	4	4	4	4	50	4	4	10	5	44	67
	28	50 30	174—00W	10.0	5.7	4	4	4	4	50	2	1	1	6	22	32
	29	50 30	172—00W	10.5	6.1	4	4	4	4	50	2	1	4	1	10	18
June	1	51 00	170—00W	9.5	4.9	4	4	4	4	50	—	2	4	—	14	20
	3	53 00	172—00W	9.5	5.3	4	4	4	4	50	12	5	11	5	33	66
	4	53 00	174—00W	10.0	5.3	4	4	4	4	50	30	—	1	4	7	42
	5	53 00	176—00W	10.0	4.8	4	4	4	4	50	2	—	6	7	27	42
	8	53 00	180	10.0	4.7	4	4	4	4	50	—	1	—	2	7	10
	10	53 00	178—00 E	9.5	5.2	4	4	4	4	50	—	3	7	15	79	104
	13	53 00	176—00 E	7.0	5.4	4	4	4	4	50	—	—	2	2	11	15
	15	56 00	175—00W	7.0	5.4	4	4	4	4	50	4	3	20	8	77	112
	16	56 00	177—00W	?	5.1	4	4	4	4	50	—	1	1	1	13	16
	18	56 00	179—00W	9.5	4.5	4	4	4	4	50	—	1	12	9	76	98
	19	56 00	179—00 E	6.5	4.2	4	4	4	4	50	3	1	10	4	67	85
	20	56 00	177—00 E	?	4.3	4	4	4	4	50	8	1	2	6	33	50
	21	56 00	175—00 E	9.0	4.8	4	4	4	4	50	1	2	9	8	52	72
	22	56 00	173—00 E	?	5.8	4	4	4	4	50	3	3	9	8	52	75
July	9	46 30	148—00 E	10.5	11.2	4	4	4	4	50				-		-
	11	47 30	150—00 E	9.5	10.4	4	4	4	4	50	—	—	—	—	-	
	14	49 00	152—00 E	9.3	8.5	4	4	4	4	?	—	—	—	—		
	15	49 00	152—00 E	9.0	9.5	4	4	4	4	50	—	—	—	—		
	16	50 30	153—00 E	9.5	8.6	4	4	4	4	50	—	—	—	—	3	3
	17	52 00	153—00 E	9.0	8.2	4	4	4	4	50	—	—	—	—	-	
	18	53 10	153—00 E	9.5	8.1	4	4	4	4	50	1	—	—	—	4	5
	20	53 10	154—30 E	9.0	8.9	4	4	4	4	50	1	—	1	7	21	30
	21	52 00	154—30 E	8.5	10.1	4	4	4	4	50	2	—	3	4	10	19
	27	58 00	180	8.0	8.0	4	4	4	4	50	1	—	2	2	31	36
	28	58 00	178—00 E	9.5	8.9	4	4	4	4	50	1	5	9	3	38	56
	29	58 00	176—00 E	9.5	8.6	4	4	4	4	50	2	2	5	—	18	27
	30	58 00	178—00 E	10.0	9.4	4	4	4	4	50	2	4	2	—	25	33
	31	58 00	172—00 E	10.0	9.5	4	4	4	4	50	—	2	2	5	9	18
Aug.	1	58 00	170—00 E	10.0	10.7	4	4	4	4	50	17	35	27	4	132	215
	2	57 00	170—00 E	10.0	10.6	4	4	4	4	50	4	20	16	4	118	162
	3	56 00	170—00 E	8.0	11.3	4	4	4	4	50	2	7	8	—	71	88
	4	55 00	170—00 E	10.0	12.8	4	4	4	4	50	—	1	2	—	14	17
	5	54 00	170—00 E	10.0	11.7	4	4	4	4	50	10	5	4	2	30	51
	7	56 00	167—30 E	10.0	12.9	4	4	4	4	47	3	8	4	1	30	46
	8	57 00	167—30 E	10.0	13.6	4	4	4	4	47	2	14	2	1	12	31
	9	58 00	167—30 E	10.0	13.2	4	4	4	4	47	36	38	13	—	36	123
	10	59 00	167—30 E	11.0	13.2	4	4	4	4	47	12	5	3	—	17	37
	11	59 00	167—30 E	10.0	13.9	4	4	4	4	47	—	9	—	—	11	20
	12	58 00	165—30 E	10.5	14.8	4	4	4	4	47	9	10	4	1	15	39
	13	58 00	165—30 E	10.5	?	4	4	4	4	47	8	14	7	—	9	38
	14	57 00	165—00 E	10.5	14.5	3	3	4	4	45	14	23	7	1	34	79
	16	56 00	165—00 E	10.5	14.3	3	3	4	4	45	4	14	1	3	12	34
	17	55 00	164—00 E	10.5	14.9	3	3	4	4	45	—	6	7	—	16	29
	18	55 00	164—00 E	10.0	?	3	3	4	4	45	—	4	12	6	30	52
	19	54 00	164—00 E	10.5	13.7	3	3	4	4	40	—	6	13	2	47	68
	20	54 00	166—00 E	10.5	13.1	3	3	4	4	42	4	10	29	4	135	182
	21	53 00	166—00 E	10.5	12.9	3	3	4	4	44	—	15	38	3	115	171
	22	53 00	164—00 E	12.0	12.7	3	3	4	4	44	—	2	13	3	89	107

[1] Length of one tan is 180 feet. [2] Mesh size in inches.

Chum						Pink						Coho						Chinook					
2½	3¼	4½	5¼	4.8	Total	2½	3¼	4½	5¼	4.8	Total	2½	3¼	4½	5¼	4.8	Total	2½	3¼	4½	5¼	4.8	Total
	4	19	33	145	201	—	—	—	1	1	2	—			—		—		—	—		—	
2	2	37	17	103	161	—	—	—	1	5	6	—	—	—	—	—	—	—	—	—	—	1	1
—	—	20	8	60	88	2	—	14	—	20	36		-	—	—		—	—			—		—
—	5	13	19	104	141	1	4	14	2	58	79	—	—	—	—	—	—	—	—	1	1	2	4
	14	40	18	125	197	—	9	7	1	33	50	—	—	—	—	—	—	—	—	1	—	1	2
	—	2	4	5	11	—	15	2	—	12	29	—	—	—	—	—	—		—	—	—	—	—
—	-	22	13	54	89	—	—	1	1	4	6	—	—	—	—	—	—	—	1	—	1	—	2
	-	2	3	6	11	—	—	—	—	6	6	—	—	—	—	—	—	—	1	4	4	18	27
	—	9	8	32	49	—	2	9	2	22	35	—		-	—		-		—	—	—		—
	1	14	3	21	39	—	—	3	—	7	10	—	—	—		—	—	—		—	—	—	—
	—	3	10	24	37	1	1	1	1	15	19	—		—	—	-	—	—			—	—	
—	1	10	8	92	111	—	3	9	—	28	40	—	—	—	—	—	—	—	—	1	—	—	1
—	—	—	—	15	15	—	—	4	—	12	16	—	—	—	—	—	—	1	—	—	2	1	4
—	1	3	9	15	28	—	—	1	—	38	39	—	—	—	—	—	—	—	—	2	—	—	2
—	—	—	7	12	19	—	—	11	3	28	42	—	—	—	-	—	—	—	—		—	—	—
	—	2	2	17	21	—	1	2	2	19	24	—		—	—		—	—		—			-
-	2	19	15	83	119	—	7	14	3	47	71	—	—	—	-	—	-	-	-		—	—	
	2	5	3	57	67	—	4	39	12	110	165	—	—	—	—	—	—	—	—	1	2	—	3
1	1	30	9	107	148	—	2	12	2	53	69	—	—	—	—	—	—	—	—	1	1	—	2
	—	6	18	39	63	1	9	72	20	210	312	—	-	—		—	—	-	—	—			
—	-	1	—	8	9	—	3	10	11	108	132	—	—	—	1	—	1	—	—	-	—	—	—
1	1	1	3	1	7	3	9	32	27	83	154	—	—	—	1	1	2	—	—	—	—	1	1
—		2	1	18	21	—	7	18	11	123	159	—	2	—	2	8	12	—	—	—	1	2	3
1	1	1	4	34	41	3	13	52	5	312	385	—	—	1	—	17	18					-	—
6	5	6	8	31	56	1	6	26	12	191	236	1	—	—	1	11	13	—	—	—	—	1	1
51	47	38	22	237	395	2	10	22	7	106	147	—	—	—	2	1	3	-					
2	4	15	24	75	120	11	53	97	50	1108	1319	—	—	4	1	8	13		—	—	—	—	—
12	22	13	7	83	137	2	17	74	46	319	458	—	—	3	—	2	5	—		-	-		—
6	6	—	—	17	29	—	—	—	—	20	20	—	1	—	—	—	1	—	1	—	—	—	1
20	17	18	10	77	142	—	—	3	—	23	26	—	—	—	—	—	—						
15	14	17	15	86	147	—	—	6	2	37	46	—	—	1	—	2	3	—	—	—	—	1	1
8	14	8	2	43	75	—	1	6	2	17	26	—	—	—	—	-		—	—	-	-	-	—
51	48	26	9	158	292	—	6	19	6	47	78	—	—	—	—	—	—	—	—	—	—	2	2
36	41	4	9	47	137	—	3	5	6	23	37	—	—	1	1	—	2	—	—	—	1	—	1
8	20	11	7	93	139	—	2	3	3	9	17	—	—	—	—	—	—	—	—	—	—	—	—
	7	2	—	31	40	—	—	2	—	3	5	—	—	—	—	5	5						
—	2	3	—	30	35	—	—	—	—	2	2	—	—	—	—	3	3	—	—	—			-
14	26	18	6	72	136	—	1	—	—	1	2	—	—	1	1	10	12			-			
—	11	7	4	18	40	—	—	1	—	2	3	—	—	—	1	—	1						
10	4		1	9	24	—	—	1	—	3	4	—	—	—	—	5	5	—	—	—	1	2	3
9	6	3	—	5	23	—	—	1	—	—	1	—	—	—	—	3	3	-	--	-			
5	3	4	4	11	27	—	3	4	1	3	11	—	1	1	2	2	6	—					
	1	9	9	12	31	—	—	1	1	1	3	—	1	1	—	8	10				-		
3	11	7	4	24	49	—	—	—	—	—	—	—	—	—	—	9	9	-					
1	5	6	7	21	42	—	—	1	—	2	3	—	—	2	1	8	11	--					
3	26	4	—	13	46	—	1	—	1	1	3	—	—	—	1	2	3	—	—	—	—	—	—
	11	9	4	52	76	—	—	—	—	—	—	—	—	2	2	4	8	--			-		
—		3	—	9	12	—	—	1	—	—	1	—	1	7	6	27	41	—	—	—	—	1	1
—	—	3	4	24	31	—	—	—	1	1	2	—	2	5	5	12	24	—	—	—	1	—	1
—	4	2	2	25	33	—	—	—	—	—	—	—	5	7	11	31	54	—	—	—	—	3	3
2	5	9	4	39	59	—	1	—	—	3	4	2	—	1	4	9	16	—	—	—	3	1	4
-	1	18	2	62	83	—		—		-	—		1	4	2	14	21				7	2	9
	5	25	7	77	114	—	—	—	—	—	—	—	2	—	1	12	15	—	—	—	1	5	6

A-31. 1959, Pioneer (U.S.)

Date	Lat.(°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of shackles of varying mesh size[1]				Sockeye				
					$2^1/_2$	$3^1/_4$	$4^1/_2$	$5^1/_4$	$2^1/_2$	$3^1/_4$	$4^1/_2$	$5^1/_4$	Total
April 24	56—01	152—59W	12.5	4.9	4	4	24	4	—	—	1	—	1
27	55—00	153—00W	62.5	4.0	3	3	11	4	—	1	11	4	16
May 20	51—29	175—03 E	14.5	4.8	4	4	24	4	—	—	21	4	25
22	51—00	175—00 E	35.0	4.7	4	4	24	4	—	1	30	10	41
23	50—00	175—00 E	12.5	5.0	4	4	24	4	—	—	14	3	17
24	49—00	175—00 E	12.0	4.7	4	4	24	4	—	2	24	2	28
25	48—00	175—00 E	12.0	5.1	4	4	24	4	—	1	34	—	35
27	49—38	171—44 E	13.2	5.0	4	4	24	4	—	—	26	1	27
28	50—25	171—20 E	9.2	5.0	4	4	24	4	—	—	16	6	22
June 3	52—00	171—00 E	13.7	5.0	4	4	24	4	—	—	15	—	15
4	52—47	171—00 E	15.0	5.6	4	4	24	4	—	1	10	5	16
5	53—30	171—00 E	15.5	5.6	4	4	24	4	—	—	27	9	36
6	54—20	171—00 E	12.0	4.5	4	4	24	4	—	—	40	15	55
8	55—00	171—00 E	40.0	5.0	4	4	24	4	—	1	49	13	63
13	53—30	180	8.5	5.0	4	4	24	4	—	—	57	11	68
22	52—38	178—47W	15.2	5.6	4	4	24	4	—	1	47	4	52
23	52—59	179—55 E	13.5	5.5	4	4	24	4	1	1	72	9	83
24	54—00	180	11.5	5.6	4	4	24	4	—	—	18	2	20
25	55—00	180	13.2	5.6	4	4	24	4	2	1	49	5	57
26	56—00	180	12.5	5.6	4	4	24	4	—	1	148	16	165
27	57—00	180	12.0	5.3	4	4	24	4	1	2	116	19	138
28	58—00	180	12.7	5.6	4	4	24	4	7	—	33	4	44
30	60—00	180	13.0	6.5	4	4	24	4	—	1	27	4	32
July 4	58—00	175—00 E	14.0	5.8	4	4	24	4	2	3	59	4	68
15	55—00	175—00 E	14.2	7.2	4	4	24	4	—	3	14	2	19
16	54—00	175—00 E	12.2	8.2	4	4	24	4	1	—	9	—	10
19	51—54	174—06 E	13.0	8.5	4	4	24	4	4	1	17	2	24
22	51—30	175—00 E	16.0	7.9	4	4	24	4	1	14	40	3	58
23	50—30	175—00 E	10.7	9.4	4	4	24	4	4	17	33	3	57
27	51—31	176—42W	13.0	7.9	4	4	24	4	126	206	138	5	475
28	51—31	176—40W	13.0	7.2	4	4	24	4	56	79	39	1	175
29	51—29	176—38W	13.2	8.0	4	4	24	4	117	217	164	9	507
Aug. 5	51—00	175—00W	14.2	10.4	4	4	24	4	63	105	195	4	367
6	50—00	175—00W	12.5	10.4	4	4	24	4	21	87	242	8	358
7	49—00	175—00W	11.0	10.6	4	4	24	4	3	19	6	—	28
9	48—00	175—00W	14.7	11.2	4	4	24	4		1		—	1
12	49—05	170—10W	11.2	10.7	4	4	24	4	—	—	1	—	1

[1] Mesh size in inches.

Chum					Pink					Coho					Chinook
2½	3¼	4½	5¼	Total	2½	3¼	4½	5¼	Total	2½	3¼	4½	5¼	Total	Total
—	—	1	—	1	—	—	—	—	—	—	—	—	—	—	—
—	—	7	—	7	—	—	—	—	—	—	—	—	—	—	—
—	1	166	18	185	—	—	—	—	—	—	—	—	—	—	—
2	1	356	59	418	—	—	—	—	—	—	—	—	—	—	1
—	—	42	—	42	—	—	—	—	—	—	—	—	—	—	—
—	3	166	8	177	—	—	—	—	—	—	—	—	—	—	—
—	33	448	7	488	—	3	99	—	102	—	—	—	—	—	1
—	—	37	—	37	—	—	—	—	—	—	—	—	—	—	—
—	—	18	1	19	—	—	—	—	—	—	—	—	—	—	1
—	—	10	1	11	—	—	—	—	—	—	—	—	—	—	1
—	—	17	3	20	—	—	4	—	4	—	—	—			
—	—	24	1	25	—	—	—	—	—	—	—	—	—	—	—
—	1	9	5	15	—	—	—	—	—	—	—	—	—	—	—
—	—	14	4	18	—	—	1	—	1	—	—	—	—	—	5
—	1	50	3	54	—	2	38	4	44	—	—	—	—	—	—
—	—	16	—	16	—	2	66	1	69	—	—	—	—	—	—
2	52	65	6	125	—	57	552	6	615	—	—	—	—	—	—
—	4	18	1	23	—	7	275	8	290	—	—	—	—	—	1
—	—	14	1	15	—	4	197	9	210	—	—	—	—	—	—
—	2	36	1	39	—	1	33	2	36	—	—	—	—	—	—
—	—	98	5	103	—	1	72	2	75	—	—	—	—	—	1
—	—	83	22	105	—	23	1149	110	1282	—	—	—	—	—	10
—	—	107	13	120	—	5	369	19	393	—	—	—	—	—	13
—	10	125	15	150	—	21	716	27	764	—	—	—	—	—	2
44	22	28	4	98	—	22	537	5	564	—	—	1	—	1	—
15	2	16	1	34	—	—	24	—	24	—	—	—	—	—	—
1	1	15	3	20	—	—	11	—	11	—	1	6	2	9	1
—	—	6	—	6	—	—	2	1	3	—	1	7	2	10	1
1	2	6	2	11	—	—	3	—	3	1	3	66	6	76	4
13	28	124	4	169	—	—	36	1	37	—	—	37	8	45	—
5	6	55	—	66	—	—	5	—	5	—	—	9	1	10	1
4	23	173	1	201	—	—	39	—	39	—	3	31	9	43	2
—	5	9	—	14	—	—	—	—	—	—	1	3	—	4	—
—	1	114	—	115	—	—	3	—	3	—	—	11	—	11	2
—	1	76	1	78	—	—	—	—	—	—	—	2	1	3	2
—	—	29	—	29	—	—	—	—	—	—	—	—	—	—	—
—	1	26	—	27	—	—	1	—	1	—	—	—	—	—	—

A-32. 1959, Tordenskjold (U.S.)

Date	Lat.(°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of shackles of varying mesh size[1]				Sockeye				
					2½	3¼	4½	5¼	2½	3¼	4½	5¼	Total
May 25	53—17	165—35W	11.2	6.0	4	4	12	4	—	1	4	3	8
26	52—40	167—37W	13.7	5.5	4	4	12	4	—	—	1	—	1
27	51—56	169—39W	12.2	5.3	4	4	12	4	1	1	36	17	55
28	51—41	171—57W	12.5	5.5	4	4	12	4	1	3	48	26	78
June 2	51—00	180	12.5	5.9	4	4	24	4	1	2	96	9	108
3	49—59	179—57W	11.7	5.3	4	4	24	4	—	—	23	—	23
4	49—03	179—56W	11.2	5.6	4	4	24	4	4	2	13	—	19
7	49—01	175—04W	11.2	5.4	4	4	24	4	—		21	1	22
12	51—32	176—31W	11.2	5.0	4	4	24	4	9		215	26	250
14	51—32	176—34W	13.2	5.3	4	4	24	4		3	46	4	53
15	51—31	176—25W	10.7	5.9	4	4	24	4	2	3	251	35	291
21	52—59	175—00W	11.2	5.8	4	4	24	4			32	6	38
22	54—00	176—00W	11.5	5.7	4	4	24	4	2	3	93	11	109
23	55—00	176—00W	10.7	6.2	4	4	24	4	—	2	85	9	96
24	56—00	176—00W	11.2	6.1	4	4	12	4	10	3	71	21	105
25	57—00	175—00W	13.2	6.7	4	4	12	4	4	6	80	29	119
27	59—00	170—00W	12.5	4.8	4	4	24	4	1	—	53	5	59
28	58—00	170—00W	11.7	5.0	4	4	24	4	—	4	35	30	69
29	56—56	170—06W	11.2	4.0	4	4	24	4	—	1	2	2	5
30	55—59	170—00W	12.7	6.8	4	4	24	4	1	1	168	32	202
July 1	55—01	170—03W	11.2	7.3	4	4	24	4	—	1	15	1	17
2	53—58	170—01W	13.0	6.6	4	4	24	4	—		20	1	21
3	53—18	170—00W	12.5	7.7	4	4	24	4	—		13	2	15
4	52—00	169—53W	10.7	8.7	4	4	24	4	71	65	102	1	239
5	51—00	169—56W	11.5	8.0	4	4	24	4	2	6	65	5	78
11	53—30	165—00W	11.7	10.0	4	4	24	4	135	139	178	8	460
12	52—58	164—56W	12.5	9.6	4	4	24	4	41	109	158	5	313
13	52—00	165—00W	11.7	8.7	4	4	24	4	18	46	132	3	199
15	50—02	165—00W	11.7	8.5	4	4	24	4	1	9	28	—	38
16	49—02	165—00W	11.2	9.1	4	4	24	4		2	3	—	5
17	48—01	165—05W	12.7	9.9	4	4	24	4	—	—	6	—	6
19	47—01	160—02W	11.7	10.2	4	4	24	4		1	—	—	1
20	48—02	160—00W	11.5	10.2	4	4	24	4	—	—	5	—	5
21	49—02	160—00W	12.2	10.2	4	4	24	4	1	2	16	1	20
22	49—55	160—05W	12.0	9.9	4	4	24	4	2	7	49	4	62
23	50—57	159—55W	11.2	10.0	4	4	24	4	12	20	103	2	137
24	51—57	159—58W	10.2	9.8	4	4	24	4	39	121	129	5	294
25	53—00	160—00W	10.5	9.9	4	4	24	4	14	35	15	2	66
26	53—55	159—40W	10.5	10.4	4	4	24	4	26	25	15	3	69

[1] Mesh size in inches.

Chum					Pink					Coho					Chinook
2½	3¼	4½	5¼	Total	2½	3¼	4½	5¼	Total	2½	3¼	4½	5¼	Total	Total
—	—	41	17	58	—	—	4	2	6	—	—	—	—	—	—
—	—	11	25	36	—	—	—	—	—	—	—	—	—	—	1
—	—	9	2	11	—	—	9	—	9	—	—	—	—	—	—
—	—	22	9	31	—	—	13	2	15	—	—	—	—	—	2
—	6	138	7	151	—	2	8	—	10	—	—	—	—	—	—
—	2	90	2	94	—	—	10	—	10	—	—	—	—	—	1
—	15	91	4	110	—	14	131	—	145	—	—	—	—	—	
—	—	45	1	46	—	12	79	—	91	—	—	—	—	—	
—	3	48	5	56	—	—	66	—	66	—	—	—	—	—	—
—	1	14	—	15	—	—	22	—	22	—	—	—	—	—	—
—	5	111	1	117	—	10	131	1	142	—	—	—	—	—	—
—	—	36	3	39	—	4	217	4	225	—	—	—	—	—	—
—	1	42	2	45	—	2	179	1	182	—	—	—	—	—	—
—	1	30	7	38	—	18	811	27	856	—	—	—	—	—	1
—	—	19	9	28	—	3	134	20	157	—	—	—	—	—	6
—	—	7	3	10	—	—	24	5	29	—	—	—	—	—	8
—	—	26	21	47	—	2	85	3	90	—	—	—	—	—	2
—	—	8	3	11	—	—	1	3	4	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	56	7	63	—	—	76	3	79	—	—	—	—	—	—
—	—	18	—	18	—	—	12	—	12	—	—	—	—	—	—
—	1	29	2	32	—	1	69	—	70	—	—	—	—	—	1
—	10	40	3	53	—	1	149	10	160	—	—	1	—	1	—
—	15	71	2	88	—	1	119	1	121	—	—	1	—	1	—
—	26	33	—	59	—	1	187	1	189	—	—	2	—	2	—
—	122	395	14	531	—	—	60	4	64	—	—	—	—	—	—
—	9	20	—	29	—	3	20	—	23	—	—	2	—	2	—
—	2	45	1	48	—	—	12	1	13	—	—	2	—	2	—
4	72	344	4	424	—	—	2	1	3	1	—	3	2	6	2
—	23	143	2	168	—	—	—	—	—	—	—	8	—	8	5
—	4	42	2	48	—	—	—	—	—	—	1	27	1	29	—
—	17	47	2	66	—	—	1	—	1	—	—	6	2	8	2
—	5	39	2	46	—	—	1	—	1	—	1	5	1	7	1
—	13	53	—	66	—	—	—	—	—	—	—	7	—	7	—
2	56	121	3	182	—	—	12	—	12	—	—	4	2	6	1
2	49	76	6	133	—	—	31	1	32	—	—	6	—	6	3
2	24	30	2	58	—	—	22	1	23	—	—	6	3	9	—
1	6	284	25	316	—	3	100	14	117	—	—	4	—	4	2
1	2	52	5	60	—	1	71	9	81	—	—	7	—	7	2

A-33. 1960, ETSUZAN-MARU (Japan)

Date		Lat. (°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of tans[1] of varying mesh size[2]					Sockeye					
						2 1/2	3 1/4	4 1/2	5 1/4	4.8	2 1/2	3 1/4	4 1/2	5 1/4	4.8	Total
May	28	49—49	170—34W		4.4	4	4	12	4	60	-	5	42	4	66	117
	29	50—00	172—30W		4.8	4	4	12	4	60	—	5	58	7	54	124
	30	50—00	175—00W		4.6	4	4	12	4	59	—	2	13	3	28	46
	31	50—00	177—30W		4.9	4	4	11	3	60	-	1	20	7	29	57
June	1	50—00	180		5.1	4	4	12	4	60	-	1	12	3	21	37
	3	50—00	175—00 E		4.7	4	4	12	4	-	-	1	16	7		24
	4	50—00	172—30 E		5.1	4	4	12	4	60	2	2	25	14	44	87
	6	48—00	168—00 E		3.7	4	4	12	4	60	1	1	28	4	12	46
	7	49—20	168—00 E		4.5	4	4	12	4	60	—	—	7	1	9	17
	8	51—00	168—00 E		4.9	4	4	12	4	60	—	4	17	11	29	61
	9	52—40	168—00 E		4.8	4	4	12	4	60	-	2	29	18	27	76
	10	54—07	169—43 E		4.3	4	4	12	4	60	4	—	22	4	46	76
	11	53—38	173—00 E		5.4	4	4	12	4	60	-	1	3	2	22	28
	12	52—55	176—49 E		5.6	4	4	12	4	60	—	—	25	5	22	52
	15	53—00	175—00W		5.3	4	4	12	4	60	2	2	58	15	91	168
	16[3]	53—00	175 –00W		5.2	4	4	12	4	23	.....	.....	341	.....	172	513
	17	53—01	172—27W		5.5	4	4	12	4	60	7	6	158	34	285	490
	18	53—15	170—00W		5.5	4	4	12	4	60	13	34	162	39	173	421
	19	54—41	170—05W		6.2	4	4	12	4	60	22	34	164	45	287	552
	20	56—00	170—00W		6.2		—		—	60	—	-			163	163
	21	56—00	172—32W		6.0	4	4	12	4	60	16	5	88	39	171	319
	22	55—55	175—02W		6.2	4	4	12	4	60	3	5	44	11	86	149
	24	54—56	179—54 E		5.6	4	4	12	4	60	2	1	18	5	35	61
	25	56—00	177—30 E		5.8	4	4	12	4	60	-	-	7	6	8	21
	27	56—00	172—30 E		6.3	4	4	12	4	60	1	5	10	6	17	39
	28	57—03	169—50 E		7.0	4	4	12	4	60	1	—	5	4	7	17
	29	54—51	169—08 E		6.4	3	3	11	3	60	—	—	9	4	16	29
July	20	47—09	149—50 E		8.6	3	3	9	3	60	-	—	—	—	1	1
	21	47—54	151—20 E		8.2	3	3	9	3	60	-	—	—		2	2
	22	49—32	153—17 E		6.7	3	3	9	3	60	—	—	17	9	49	75
	26	55—24	163—50 E		9.5	3	3	9	3	60	33	65	55	4	50	207
	27	56—59	164—59 E		10.5	3	3	9	3	60	3	13	30	4	27	77
	28	58—29	167—30 E		10.5	3	3	9	3	60	7	31	56	1	63	158
	29	59—00	170—00 E		9.0	3	3	9	3	60	6	17	75	3	35	136
	30	59—00	172—30 E		9.4	4	4	12	4	60	6	10	52	5	30	103
	31	57—30	172—30 E		9.5	4	4	12	4	60	4	8	35	3	22	72
Aug.	1	57—30	170—00 E		9.6	3	3	9	3	60	2	11	28	3	35	79
	2	57—30	167—30 E		10.5		-	—		60		-		-	37	37
	3	56—00	167—30 E		10.8	3	3	9	3	60	-	2	1		4	7
	4	56—00	170—00 E		10.8	3	3	9	3	60	11	21	13	3	44	92
	5	56—00	172—30 E		10.4	4	4	12	4	60	2	5	31	2	19	59
	6	54—30	172—30 E		10.4	3	3	9	3	60	1	2	21	2	20	46
	8	54—43	170—12 E		10.0	3	3	9	3		-	1	36	—		37
	9	53—37	167—41 E		10.6	3	3	9	3	60	2	8	39	2	30	81
	10	53—30	165—00 E		11.5	3	3	9	3	60	1	8	78	5	55	147
	11	53—30	162—30 E		11.6	4	4	12	4	60	4	5	24	4	35	72
	12	52—00	162—29 E		12.0			—		60		—			55	55
	14	52—00	165—00 E		11.5	4	4	12	4	-		8	97	6	—	111
	15	52—00	167—30 E		11.0	4	4	12	4			1	15	3	—	19
	16	52—00	169—30 E		10.4	4	4	12	4		3	11	45	2	—	61
	17	50—32	170—04 E		10.5	4	4	12	4		-	1	13	1	—	15
	18	50—30	167—30 E		10.8	4	4	12	4	60	1	1	9	2	6	19

[1] Length of one tan is 180 feet. [2] Mesh size in inches. [3] Catches by various mesh sized gillnets were combined.

Chum						Pink						Coho						Chinook					
2½	3¼	4½	5¼	4.8	Total	2½	3¼	4½	5¼	4.8	Total	2½	3¼	4½	5¼	4.8	Total	2½	3¼	4½	5¼	4.8	Total
—	1	18	3	24	46	—	8	—	—	—	8	—	—	—	—	—	—	—	—	—	—	—	—
—	1	27	9	21	58	—	15	7	—	2	24	—	—	—	—	—	—	—	—	—	—	—	—
—	—	5	3	9	17	—	3	4	—	3	10	—	—	—	—	—	—	—	—	—	—	—	—
—	—	19	1	22	42	—	3	3	—	—	6	—	—	—	—	—	—	—	—	—	1	—	1
—	—	29	4	64	97	—	10	4	—	1	15	—	—	—	—	—	—	—	—	—	—	—	—
—	—	33	3	—	36	—	12	3	—	—	15	—	—	—	—	—	—	—	—	—	—	—	—
—	—	33	3	57	93	—	8	2	—	2	12	—	—	—	—	—	—	—	—	1	1	—	2
—	—	4	4	8	16	—	3	2	—	—	5	—	—	—	—	—	—	—	—	—	—	—	—
—	—	7	—	12	19	—	2	5	—	—	7	—	—	—	—	—	—	—	—	—	—	—	—
—	—	18	5	21	44	—	4	13	—	1	18	—	—	—	—	—	—	—	—	—	—	—	—
—	3	46	9	28	86	—	14	27	—	3	44	—	—	—	—	—	—	—	—	—	—	—	—
—	1	31	17	80	129	—	6	5	—	1	12	—	—	—	—	—	—	—	—	—	2	—	2
—	2	56	17	34	109	—	11	6	—	6	23	—	—	—	—	—	—	—	—	1	3	1	5
—	—	4	—	3	7	—	5	3	—	—	8	—	—	—	—	—	—	—	—	—	—	—	—
—	—	8	3	17	28	—	1	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
.....	29	.....		5	34	.....	5	.....		3	8	—	—	—	—	—	—	—	—	—	—	—	—
—	—	8	1	15	24	—	—	1	—	2	3	—	—	—	—	—	—	—	—	—	—	—	—
1	—	33	13	29	76	—	—	4	—	1	5	—	—	—	—	—	—	—	—	—	—	—	—
—	6	9	7	27	49	—	3	3	—	1	7	—	—	—	—	—	—	—	—	1	1	2	4
—	—	—	—	53	53	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	1	6	—	6	13	—	1	3	1	1	6	—	—	—	—	—	—	—	—	—	—	1	1
—	1	37	4	35	77	—	3	20	—	4	27	—	—	—	—	—	—	—	5	—	1	2	8
—	—	20	4	13	37	—	1	2	—	—	3	—	—	—	—	—	—	—	—	1	—	—	1
—	1	14	—	15	30	—	7	12	2	6	27	—	—	—	—	—	—	—	—	—	—	—	—
1	—	35	1	22	59	—	10	42	—	9	61	—	—	—	—	—	—	—	—	—	1	—	1
—	2	12	9	16	39	—	4	48	—	20	72	—	—	—	—	—	—	—	2	7	1	—	10
—	2	10	1	6	19	—	6	17	2	6	31	—	—	—	—	—	—	—	—	—	—	—	—
—	—	18	9	45	72	—	1	34	10	109	154	—	—	1	—	6	7	—	—	—	—	1	1
—	1	19	8	51	79	1	3	89	11	215	319	—	—	2	—	2	4	—	—	—	—	—	—
—	2	35	10	48	95	—	2	74	20	100	196	1	—	4	1	8	14	—	—	—	—	—	—
11	25	17	6	28	87	—	—	1	1	—	2	1	—	1	1	—	3	—	—	1	—	—	1
17	38	78	8	67	208	—	—	1	—	6	7	—	—	—	1	—	1	—	—	—	—	—	—
24	23	69	9	74	199	—	—	1	—	—	1	—	—	1	—	1	2	—	—	—	—	—	—
25	9	92	8	112	246	—	—	1	—	1	2	—	—	—	—	—	—	—	—	—	1	—	1
54	73	116	12	49	300	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
61	37	108	6	76	288	—	—	—	—	—	—	—	1	—	—	1	2	—	—	1	1	—	2
8	16	57	8	63	152	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	2
—	—	—	—	35	35	—	—	—	—	—	—	—	—	—	—	3	3	—	—	—	—	—	—
3	2	20	3	22	50	—	—	1	—	1	2	—	—	—	—	1	1	—	—	—	—	—	—
6	8	21	2	60	97	—	—	—	—	1	1	—	—	—	—	1	1	—	—	1	—	—	1
24	16	45	2	27	114	—	—	1	—	—	1	—	—	—	—	1	1	—	—	—	—	—	—
5	9	42	3	32	91	—	—	—	—	—	—	—	—	1	—	—	1	—	—	1	—	3	4
—	2	15	4	—	21	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	2	6	5	21	34	—	—	1	—	—	1	—	1	2	—	10	13	—	—	—	—	—	—
—	3	22	5	36	66	1	—	—	—	1	2	—	—	7	4	34	45	—	—	1	—	—	1
—	3	45	3	30	81	—	—	—	—	3	3	—	1	10	7	20	38	—	—	—	—	—	—
—	—	—	—	43	43	—	—	—	—	1	1	—	—	—	—	11	11	—	—	—	—	—	—
2	2	49	1	—	54	—	—	—	—	—	—	—	—	7	7	—	14	—	—	1	—	—	1
—	—	17	12	—	29	—	—	—	—	—	—	—	—	9	3	—	12	—	—	1	1	—	2
1	2	48	6	—	57	—	—	—	1	—	1	—	—	3	3	—	6	—	—	—	2	—	2
1	1	20	2	—	24	—	—	—	—	—	—	—	—	12	3	—	15	—					
—	—	8	—	20	28	—	—	1	—	1	2	—	—	3	4	10	17	—	1	—	—	—	1

A-34. 1960, Paragon (U.S.)

Date		Lat.(°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of shackles of varying mesh size[1]				Sockeye				
						2½	3¼	4½	5¼	2½	3¼	4½	5¼	Total
May	18	52—50	167—06W	11.0	5.4	4	4	24	4	—	—	6	—	6
	19	52—25	168—31W	13.2	5.8	4	4	24	4	—	—	1	—	1
	22	52—00	169—59W	13.0	4.5	4	4	24	4	—	—	1	4	5
	23	51—04	170—49W	10.5	5.2	4	4	24	4	—	2	212	21	235
	24	50—06	171—40W	10.7	4.4	4	4	24	4	—	—	87	7	94
	27	47—03	174—10W	13.0	4.6	4	4	24	4	—	—	4	—	4
	28	46—00	174—59W	12.5	5.4	4	4	24	4	1	7	6	—	14
	29	45—00	175—00W	12.0	6.5	4	4	24	4	3	27	28	2	60
	31	47—00	177—11W	21.7	5.3	4	4	24	4	—	—	4	—	4
June	1	47—44	177—46W	8.5	5.1	4	4	24	4	—	1	14	—	15
	4	49—01	180	13.0	4.4	4	4	24	4	—	—	5	1	6
	5	50—02	179—59 E	12.0	4.6	4	4	24	4	—	1	47	3	51
	6	51—00	179—59 E	12.7	5.3	4	4	24	4	2	5	302	42	351
	7	51—04	178—30W	11.0	5.4	4	4	24	4	1	—	159	14	174
	15	53—00	176—10W	13.5	5.1	4	4	24	4	2	5	245	26	278
	16	54—01	175—38W	13.5	5.5	4	4	24	4	—	2	271	9	282
	17	55—00	175—01W	12.5	5.8	4	4	12	4	—	—	5	3	8
	18	56—01	175—00W	13.2	5.8	4	4	24	4	—	2	62	3	67
	19	57—01	174—59W	12.7	5.7	4	4	24	4	—	2	59	10	71
	20	56—42	173—27W	12.7	5.7	4	4	24	4	—	2	247	31	280
	21	56—21	171—41W	12.0	5.8	4	4	12	4	—	5	122	43	170
	22	55—58	169—59W	12.7	6.2	4	4	12	4	3	13	216	27	259
	23	55—00	170—01W	12.7	6.4	4	4	12	4	—	2	92	7	101
	24	54—00	169—59W	12.2	6.2	4	4	24	4	1	3	183	9	196
	25	53—20	169—59W	10.7	6.2	4	4	24	4	—	3	178	14	195
	26	52—15	169—57W	11.5	6.8	4	4	24	4	1	—	85	12	98
	27	51—18	170—37W	10.7	6.6	4	4	24	4	3	1	75	4	83
	28	50—07	171—43W	12.2	7.0	4	4	24	4	2	29	66	4	101
	29	49—05	172—31W	10.5	6.7	4	4	24	4	—	6	13	—	19
July	7	53—44	173—00W	13.5	7.7	4	4	24	4	—	2	52	5	59
	8	53—26	173—01W	13.7	7.6	4	4	24	4	—	1	24	1	26
	9	53—06	173—01W	13.2	7.4	4	4	24	4	—	1	1	—	2
	11	51—29	173—04W	13.7	8.9	4	4	24	4	3	25	147	8	183
	12	51—09	173—01W	14.0	8.9	4	4	24	4	4	20	83	7	114
	13	50—50	172—59W	13.2	8.6	4	4	24	4	2	14	54	2	72
	15	50—29	173—00W	13.5	8.6	4	4	24	4	2	9	22	—	33
	17	50—29	170—00W	13.7	11.0	4	4	24	4	10	10	47	3	70
	18	50—54	170—02W	13.7	10.9	4	4	24	4	31	39	151	10	231
	19	51—13	170—02W	13.5	10.8	4	4	24	4	10	29	92	1	132
	20	51—32	170—01W	13.5	11.1	4	4	24	4	10	22	96	10	138
	21	51—51	169—59W	11.5	11.0	4	4	24	4	49	78	173	6	306
	23	52—15	170—00W	10.7	11.0	4	4	24	4	15	15	58	1	89
	25	53—05	166—05W	10.5	9.6	4	4	24	4	1	3	35	4	43

[1] Mesh size in inches.

Chum					Pink					Coho					Chinook
2 1/2	3 1/4	4 1/2	5 1/4	Total	2 1/2	3 1/4	4 1/2	5 1/4	Total	2 1/2	3 1/4	4 1/2	5 1/4	Total	Total
—	—	13	3	16	—	—	1	1	2	—	—	—	—	—	1
—	—	35	9	44	—	—	2	—	2	—	—	—	—	—	—
—	—	40	5	45	—	—	—	—	—	—	—	—	—	—	—
—	—	55	8	63	—	1	22	—	23	—	—	—	—	—	—
—	—	20	2	22	—	7	12	1	20	—	—	—	—	—	—
—	5	81	—	86	—	6	34	1	41	—	—	—	—	—	—
—	4	12	—	16	—	5	16	—	21	—	—	—	—	—	—
—	2	2	—	4	—	3	3	—	6	—	2	—	—	2	—
1	10	61	1	73	—	8	13	—	21	—	—	—	—	—	—
—	6	33	4	43	—	4	5	—	9	—	—	—	—	—	—
—	3	63	1	67	—	1	7	—	8	—	—	—	—	—	—
—	—	90	4	94	—	5	4	—	9	—	—	—	—	—	—
—	10	166	6	182	—	13	14	—	27	—	—	—	—	—	—
—	2	23	1	26	—	3	2	—	5	—	—	—	—	—	—
—	—	15	—	15	—	7	28	—	35	—	—	—	—	—	—
—	—	19	1	20	—	—	8	1	9	—	—	—	—	—	6
—	—	6	3	9	—	1	13	—	14	—	—	—	—	—	6
—	—	15	3	18	—	—	15	—	15	—	—	—	—	—	2
—	—	49	16	65	—	4	76	1	81	—	—	—	—	—	9
—	1	69	1	71	—	—	12	—	12	—	—	—	—	—	4
—	1	49	8	58	—	—	2	—	2	—	—	—	—	—	—
—	—	13	—	13	—	—	—	—	—	—	—	—	—	—	1
—	—	9	2	11	—	1	1	—	2	—	—	—	—	—	—
—	6	183	9	198	—	1	13	—	14	—	—	—	—	—	1
—	—	87	7	94	—	2	3	—	5	—	—	—	—	—	—
—	6	153	6	165	—	—	12	—	12	—	—	—	—	—	—
—	1	57	1	59	—	1	1	—	2	—	—	—	—	—	—
—	6	78	5	89	—	2	7	—	9	—	—	—	—	—	—
—	23	73	8	104	—	—	1	—	1	—	—	—	—	—	—
—	2	39	1	42	—	1	2	—	3	—	—	—	—	—	6
—	5	13	2	20	—	—	1	—	1	—	—	—	—	—	2
—	—	2	—	2	—	—	—	—	—	—	—	—	—	—	—
1	4	11	1	17	—	—	3	—	3	—	12	—	—	12	1
1	5	5	—	11	—	—	2	1	3	—	2	—	—	2	—
1	11	37	2	51	—	—	11	—	11	—	3	—	2	5	—
3	16	37	1	57	—	—	18	—	18	—	19	—	2	21	1
4	8	37	4	53	—	—	24	1	25	—	11	—	1	12	—
1	31	85	2	114	—	—	28	2	30	—	18	—	3	21	1
—	4	59	—	63	—	1	20	2	23	—	8	—	1	9	—
—	24	46	2	72	—	—	14	1	15	—	10	—	1	11	—
1	100	495	13	609	—	1	70	7	78	—	10	—	—	10	—
—	144	396	1	541	—	—	61	2	63	—	8	—	—	8	—
2	132	1064	17	1215	—	1	70	5	76	—	3	—	2	5	—

A-35. 1960, Pioneer (U.S.)

Date	Lat.(°N)	Long.	Fishing time (hours)	Surf. temp. (°C)	No. of shackles of varying mesh size[1]				Sockeye				
					2½	3¼	4½	5¼	2½	3¼	4½	5¼	Total
May 28	50—07	170—04 E	9.5	3.9	4	4	24	4	2	—	44	15	61
29	51—00	170—00 E	12.0	4.3	4	4	24	4	—	1	9	2	12
30	52—00	170—00 E	14.5	5.2	4	4	24	4	—	—	27	9	38
31	53—02	170—00 E	13.0	4.9	4	4	24	4	2	1	16	12	31
June 5	54—03	171—04 E	8.0	4.0	4	4	24	4	—	2	5	4	11
6	53—58	172—45 E	13.0	4.8	4	4	24	4	—	—	10	1	11
7	53—48	174—13 E	12.0	4.6	4	4	24	4	—	—	7	1	8
8	53—37	175—54 E	7.0	4.8	4	4	24	4	1	2	35	3	41
9	53—14	178—08 E	8.2	5.3	4	4	24	4	—	—	4	2	6
10	52—52	179—51W	10.7	5.2	4	4	24	4	—	1	6	1	8
11	52—24	178—00W	12.5	6.0	4	4	24	4	—	—	21	7	28
18	53—00	176—58W	13.2	5.7	4	4	24	4	1	—	100	23	124
19	54—03	177—05W	11.0	5.4	4	4	24	4	—	5	173	26	204
20	55—01	176—58W	13.7	5.4	4	4	24	4	—	1	111	24	136
21	55—00	178—52W	13.5	6.7	4	4	24	4	1	2	20	1	24
23	54—57	179—23 E	15.5	5.9	4	4	24	4	—	2	29	12	43
25	54—59	174—57 E	23.0	6.1	4	4	24	4	—	1	8	1	10
27	53—00	175—00 E	14.0	6.2	4	4	24	4	—	—	12	1	13
29	50—59	174—55 E	12.5	6.7	4	4	24	4	2	8	76	5	91
30	50—01	175—03 E	12.7	6.6	4	4	24	4	3	37	68	—	108
July 2	49—01	179—56W	13.7	6.9	4	4	24	4	1	6	14	1	22
3	50—02	178—36W	12.5	6.9	4	4	24	4	1	12	39	2	54
4	51—20	176—45W	8.0	7.5	4	4	24	4	1	12	79	3	95
14	53—18	173—12 E	12.5	7.7	4	4	24	4	1	4	24	1	30
16	52—22	172—50 E	14.0	8.5	4	4	24	4	6	33	172	6	217
17	52—00	173—00 E	12.5	8.4	4	4	24	4	3	11	73	2	89
18	51—39	173—02 E	14.0	8.5	4	4	24	4	3	18	114	4	139
19	51—20	173—00 E	15.0	8.7	4	4	24	4	2	1	67	3	73
27	51—20	178—00 E	13.5	7.1	4	4	24	4	—	1	147	4	152
28	51—00	178—00 E	13.0	8.6	4	4	24	4	9	36	286	7	338
29	50—39	178—02 E	13.7	9.1	4	4	24	4	—	14	220	9	243
Aug. 1	50—20	178—00 E	61.0	9.1	4	4	24	4	2	36	184	3	225
14	51—28	176—30W	13.7	9.3	4	4	24	4	10	61	326	19	416
17	51—00	176—30W	12.5	9.8	4	4	24	4	6	22	225	8	261
18	50—40	176—30W	13.0	10.1	4	4	24	4	3	26	212	12	253
20	50—20	176—30W	36.0	10.1	4	4	24	4	3	17	210	5	235
24	52—43	159—58W	10.5	11.6	4	4	24	4	—	—	2	—	2
25	53—15	160—00W	13.5	11.9	4	4	24	4	—	—	4	2	6
26	54—17	160—00W	19.0	10.9	4	4	24	4	—	—	2	2	4

[1] Mesh size in inches.

Chum					Pink					Coho					Chinook
2½	3¼	4½	5¼	Total	2½	3¼	4½	5¼	Total	2½	3¼	4½	5¼	Total	Total
—	—	19	2	21	—	1	—	—	1	—	—	—	—	—	—
—	—	13	1	14	—	—	30	1	32	—	—	—	—	—	—
—	—	89	7	96	—	2	23	—	25	—	—	—	—	—	—
—	—	19	2	21	—	—	6	—	6	—	—	—	—	—	—
—	—	35	12	47	—	1	9	—	10	—	—	—	—	—	1
—	—	10	4	14	—	—	5	—	5	—	—	—	—	—	1
—	—	4	—	4	—	—	11	—	11	—	—	—	—	—	—
—	—	62	8	70	—	8	29	—	37	—	—	—	—	—	—
—	1	15	2	18	—	2	13	—	15	—	—	—	—	—	1
—	1	7	1	9	—	—	4	—	4	—	—	—	—	—	—
—	—	16	2	18	—	—	—	—	—	—	—	—	—	—	—
—	—	12	—	12	—	—	9	2	11	—	—	—	—	—	—
—	—	30	—	30	—	—	1	—	1	—	—	—	—	—	—
—	—	35	2	37	—	—	2	—	2	—	—	—	—	—	—
—	1	80	8	89	—	3	61	1	65	—	—	—	—	—	1
—	—	3	2	5	—	—	5	—	5	—	—	—	—	—	—
—	—	29	1	30	—	—	33	3	36	—	—	—	—	—	1
—	3	220	3	226	—	—	19	—	19	—	—	—	—	—	—
—	13	42	3	58	—	—	5	—	5	—	—	—	—	—	—
—	1	13	1	15	—	—	5	—	5	—	—	1	1	2	—
4	4	13	1	22	—	—	—	—	—	—	—	1	—	1	1
—	5	22	4	31	—	—	2	—	2	—	—	1	2	3	—
—	19	44	1	64	—	—	3	—	3	—	—	1	—	1	1
12	12	25	1	50	—	—	—	—	—	—	—	—	—	—	—
14	13	64	4	91	—	—	2	—	2	—	—	1	—	1	—
15	8	53	1	76	—	—	2	—	2	—	—	—	—	—	—
58	24	26	4	112	—	—	2	—	2	—	—	7	—	7	—
6	1	6	1	14	—	—	—	—	—	—	—	1	3	4	—
3	12	58	1	74	—	—	11	2	13	—	—	4	2	6	—
—	1	25	1	27	—	—	4	—	4	—	—	13	—	13	—
—	3	29	1	33	—	—	1	—	1	—	1	35	11	47	5
—	4	27	—	31	—	—	1	—	1	—	—	40	15	55	—
1	6	77	1	85	—	—	3	1	4	—	—	3	2	5	1
—	4	88	6	98	—	—	—	—	—	—	—	9	1	10	—
1	5	86	1	93	—	—	—	—	—	—	—	4	3	7	—
—	2	34	—	36	—	—	1	—	1	—	—	—	1	1	—
—	1	37	1	39	—	—	—	—	—	—	—	1	—	1	—
—	1	25	1	27	—	—	—	1	1	—	—	1	—	1	—
1	1	1	3	6	—	—	3	—	3	—	—	2	—	2	—

APPENDIX TABLE B. AGE AND MATURITY COMPOSITION (UNWEIGHTED) OF SOCKEYE AND CHUM SALMON CAUGHT BY INPFC GILLNET RESEARCH VESSELS, BY DATE AND STATISTICAL AREA, 1955–1960. DATA PROVIDED BY CANADA ALSO INCLUDE AGES OF COHO AND CHINOOK SALMON.

(Data according to the categories in this table are not available for Japanese vessels operating in 1955, 1956 and 1958, nor for the United States vessel *John N. Cobb* in 1956. In the table, "*M*" represents maturing, "*I*" represents immature and "?" represents degree of maturation or age unknown.)

		Page
B- 1.	1955, *John N. Cobb* (U.S.)	197
B- 2.	1955, *Mitkof* (U.S.)	198
B- 3.	1955, *Paragon* (U.S.)	199
B- 4.	1956, *Challenger* (Canada)	200
B- 5.	1956, *Key West II* (Canada)	201
B- 6.	1956, *Celtic* (U.S.)	202
B- 7.	1956, *Mitkof* (U.S.)	203
B- 8.	1956, *Paragon* (U.S.)	204
B- 9.	1956, *Tordenskjold* (U.S.)	205
B-10.	1957, *Fort Ross* (Canada)	206
B-11.	1957, *Key West II* (Canada)	207
B-12.	1957, *Etsuzan-maru* (Japan)	208
B-13.	1957, *Kano-maru* (Japan)	209
B-14.	1957, *Attu* (U.S.)	210
B-15.	1957, *Paragon* (U.S.)	211
B-16.	1957, *Pioneer* (U.S.)	212
B-17.	1958, *Fort Ross* (Canada)	213
B-18.	1958, *Key West II* (Canada)	213
B-19.	1958, *Attu* (U.S.)	214
B-20.	1958, *Pioneer* (U.S.)	215
B-21.	1959, *Fort Ross* (Canada)	216
B-22.	1959, *Key West II* (Canada)	217
B-23.	1959, *Kano-maru* (Japan)	218
B-24.	1959, *Pioneer* (U.S.)	219
B-25.	1959, *Tordenskjold* (U.S.)	220
B-26.	1960, *Etsuzan-maru* (Japan)	221
B-27.	1960, *Paragon* (U.S.)	222
B-28.	1960, *Pioneer* (U.S.)	223

Date		Statistical area	Maturity: Sockeye I	Sockeye M	Sockeye ?	Chum I	Chum M	Chum ?	Age: Sockeye 3_2	4_3	5_4	3_1	4_2	5_3	6_4	4_1	5_2	6_3	7_4	Other	?	Total	Chum 2	3	4	5	6	?	Total
June	26	W3548	—	1	1	No data			—	—	—	—	1	—	—	—	—	—	—	—	1	2	No data						
	27	W3550	—	4	1	—	1	—	1	—	—	—	2	—	—	—	1	—	—	—	1	5	—	1	—	—	—	—	1
July	1	W4052	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	1
	2	W3552	—	1	—	No data			—	—	—	—	—	1	—	—	—	—	—	—	—	1	No data						
	3	W4054	—	4	3	7	5	—	—	—	—	—	1	—	—	—	3	—	—	—	3	7	—	10	2	—	—	—	12
	4	W4054	—	9	1	2	4	—	—	—	—	—	2	2	—	—	5	—	—	—	1	10	1	1	4	—	—	—	6
	7	W4056	—	2	—	—	3	—	—	—	—	—	—	—	—	—	2	—	—	—	—	2	—	—	2	1	—	—	3
	8	W4056	—	8	6	—	1	—	—	—	—	—	5	—	—	—	3	—	—	—	6	14	—	—	1	—	—	—	1
	12	W4056	—	12	18	10	24	—	—	—	—	—	4	1	—	—	6	1	—	—	18	30	1	11	20	2	—	—	34
	13	W4556	—	5	6	8	7	—	—	—	—	—	—	2	—	—	—	2	—	—	7	11	—	6	9	—	—	—	15
	14	W4556	—	17	1	10	8	—	—	—	—	—	4	4	3	—	2	2	—	1	2	18	—	2	15	1	—	—	18
	15	W5056	—	2	—	1	1	—	—	—	—	—	—	—	—	—	2	—	—	—	—	2	—	1	1	—	—	—	2
	16	W5056	—	1	—	No data			—	—	—	—	—	1	—	—	—	—	—	—	—	1	No data						
	17	W5056	7	3	6	36	18	—	2	—	—	—	5	—	—	—	1	2	—	—	6	16	—	18	35	1	—	—	54
	18	W5556	2	5	3	31	21	—	1	—	—	—	2	2	1	—	—	1	—	—	3	10	—	9	43	—	—	—	52
	22	W5554	—	2	6	3	4	—	—	—	—	—	—	2	—	—	—	—	—	—	6	8	—	2	4	1	—	—	7
	23	W5554	3	2	—	3	11	—	1	—	—	—	2	2	—	—	—	—	—	—	—	5	—	4	10	—	—	—	14
	24	W5552	4	—	5	4	2	—	—	1	—	—	2	1	—	—	—	—	—	—	5	9	—	3	3	—	—	—	6
	25	W5552	3	—	2	4	2	—	2	—	—	—	—	1	—	—	—	—	—	—	2	5	—	1	5	—	—	—	6
	26	W6052	15	1	6	14	3	—	—	—	—	—	4	10	1	—	—	1	—	—	6	22	—	5	12	—	—	—	17
	27	W6052	4	—	3	1	—	—	—	—	—	—	3	1	—	—	—	—	—	—	3	7	—	—	1	—	—	—	1
	30	W6552	7	1	11	2	—	—	4	—	—	—	2	1	—	—	—	—	—	—	12	19	—	2	—	—	—	—	2
	31	W6552	5	—	—	No data			1	2	—	—	2	—	—	—	—	—	—	—	—	5	No data						
Aug.	1	W7052	9	—	9	1	—	—	2	—	—	—	3	4	—	—	—	—	—	—	9	18	—	1	—	—	—	—	1
	2	W7052	29	2	16	No data			17	10	1	—	—	2	—	—	1	—	—	—	16	47	No data						
	5	W6552	9	1	11	40	4	—	3	3	—	—	2	2	—	—	—	—	—	—	11	21	6	16	22	—	—	—	44
	6	W6054	6	1	4	1	—	—	1	1	1	—	3	1	—	—	—	—	—	—	4	11	—	—	1	—	—	—	1
	10	W5556	2	1	1	23	35	—	—	—	—	—	1	1	—	—	—	1	—	—	1	4	2	30	24	2	—	—	58
	11	W5056	6	1	6	16	16	—	—	—	—	—	5	1	—	1	—	—	—	—	6	13	2	17	13	—	—	—	32
	12	W5056	1	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—
	17	W4556	—	—	2	6	1	—	—	—	—	—	—	—	—	—	—	—	—	—	2	2	2	3	2	—	—	—	7
	18	W4556	2	1	9	9	5	—	—	—	—	—	3	—	—	—	—	—	—	—	9	12	—	9	5	—	—	—	14
	19	W4556	—	—	—	7	23	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	12	15	1	—	—	30
	20	W4056	1	1	1	10	62	—	—	—	—	—	2	—	—	—	—	—	—	—	1	3	3	26	41	2	—	—	72
	20*	W4056	—	—	1	—	6	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	1	4	1	—	—	6
	21	W4056	—	—	—	No data			—	—	—	—	—	—	—	—	—	—	—	—	—	—	No data						
	22	W4056	—	2	—	—	19	—	—	—	—	—	1	—	—	—	1	—	—	—	—	2	—	5	13	1	—	—	19
	22*	W4056	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—	2
	23	W4056	—	—	—	No data			—	—	—	—	—	—	—	—	—	—	—	—	—	—	No data						
	27	W4054	—	—	—	—	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5	—	—	—	5
	29	W4054	—	—	—	10	17	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	11	16	—	—	—	27
	30	W4054	—	—	—	25	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5	17	5	—	—	—	27
Sept.	6	W4056	—	—	—	—	8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4	4	—	—	—	8
	7	W4056	—	—	—	42	41	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	53	29	1	—	—	83
	8	W4556	—	—	—	57	16	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	9	47	17	—	—	—	73
	9	W4556	—	—	—	3	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	1	3	—	—	—	6
	10	W5056	—	—	—	5	6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4	4	3	—	—	—	11
	10*	W5056	—	—	2	2	1	—	—	—	—	—	—	—	—	—	—	—	—	—	2	2	—	2	1	—	—	—	3
	12	W4556	1	—	2	7	4	—	1	—	—	—	—	—	—	—	—	—	—	—	2	3	1	7	3	—	—	—	11
	13	W4554	—	—	—	13	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4	7	2	—	—	—	13

* Day set.

B-2. 1955, Mitkof (U.S.)

Date		Statistical area	Maturity: Sockeye I	Sockeye M	Sockeye ?	Chum I	Chum M	Chum ?	Age: Sockeye 3_2	4_3	5_4	3_1	4_2	5_3	6_4	4_1	5_2	6_3	7_4	Other	?	Total	Chum 2	3	4	5	6	?	Total
Aug.	12	W6552	18	—	4	No data			3	2	1	—	10	1	1	—	1	—	—	—	3	22	2	20	6	—	—	—	28
	13	W6550	19	—	22	〃	〃		1	2	—	—	25	7	—	—	—	—	—	—	6	41	4	6	6	—	—	—	16
	14	W7050	1	—	2	〃	〃		—	—	—	—	1	—	—	—	—	—	—	—	2	3	4	5	6	—	—	—	15
	15	W7048	—	—	1	〃	〃		—	—	—	—	1	—	—	—	—	—	—	—	—	1	1	1	—	—	—		2
	16	W6548	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		—
	17	W6546	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		—	—
	18	W6546																											
	19	W7044	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
	20	W7044	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—			
	21	W7544	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	22	W7044	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
	23	W7046	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
	24	W7546	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
	25	W7548	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	26	W7550	4	—	1	No data			—	1	—	—	3	—	—	—	—	—	—	—	1	5	—	1	2	—	—	—	3
Sept.	3	W7550	15	1	6	〃	〃		2	1	1	—	11	4	—	—	1	—	—	—	2	22	—	3	3	—	—	—	6
	4	8048	—	—	4	〃	〃		—	1	—	—	—	1	—	—	—	—	—	—	2	4	—	1	—	—	—	—	1
	7	W7548	2	—	2	〃	〃		—	—	—	—	2	—	—	—	—	—	—	—	2	4	—	5	5	—	—	—	10
	22	W5550	9	—	1	〃	〃		4	2	—	—	1	3	—	—	—	—	—	—	—	10	—	—	2	—	—	—	2
	23	W5550	9	—	1	〃	〃		4	—	—	—	5	1	—	—	—	—	—	—	—	10	—	1	1	—	—	—	2
	24	W5548	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	25	W5546	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		—
	28	W4546																											
Oct.	1	W3546	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		—
	3	W3046	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
	5	W3048	—	—	—	No data			—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	2

B-3. 1955, Paragon (U.S.)

Date		Statistical area	Maturity						Age																				
			Sockeye			Chum			Sockeye															Chum						
			I	*M*	?	*I*	*M*	?	3_2	4_3	5_4	3_1	4_2	5_3	6_4	4_1	5_2	6_3	7_4	Other	?	Total	2	3	4	5	6	?	Total
Aug.	13	W7550	24	—	3	13	—	1	5	4	—	—	12	4	—	—	—	—	—	—	2	27	4	4	6	—	—	—	14
	14	W7548	1	—	1	13	—	2	—	—	—	—	2	—	—	—	—	—	—	—	—	2	—	10	5	—	—	—	15
	15	W7548	2	1	—	6	—	2	—	—	—	—	3	—	—	—	—	—	—	—	—	3	—	4	4	—	—	—	8
	16	W7546	—	—	—	23	6	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	14	19	—	—	—	33
	17	W7546	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	18	W7544	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	19	8044	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	20	8044	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	21	E 7544	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	22	E 7544	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	23	E 7546	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	24	E 7546	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	25	E 7548	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	26	E 7548	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	27	E 7550	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	1	—	—	—	—	—	—	—
	28	E 7550	9	—	2	55	3	—	8	1	—	—	2	—	—	—	—	—	—	—	—	11	—	38	20	—	—	—	58
Sept.	3	8050	13	—	3	98	1	11	6	2	—	—	5	1	1	—	1	—	—	—	—	16	1	39	68	2	—	—	110
	4	8048	1	—	5	81	3	6	3	—	—	—	2	1	—	—	—	—	—	—	—	6	—	33	55	2	—	—	90
	13	E 7550	3	—	1	29	2	2	2	—	—	—	—	1	—	—	—	—	—	—	1	4	—	2	31	—	—	—	33
	14	E 7048	—	—	—	No data			—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	7	35	1	—	—	43
	15	E 7046	—	—	—	No data			—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	1	—	—	3
	16	E 7546	—	—	—	10	1	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	11	1	—	—	13
	17	E 7546	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	2
	19	8048	—	—	—	23	—	7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6	24	—	—	—	30
	20	W7550	2	—	1	10	3	1	2	—	—	—	1	—	—	—	—	—	—	—	—	3	—	5	9	—	—	—	14
Oct.	3	W4550	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

B-4. 1956, Challenger (Canada)

Date		Statistical area	Maturity: Sockeye I	Sockeye M	Sockeye ?	Chum I	Chum M	Chum ?	Age: Sockeye 2_1	3_2	4_3	5_4	3_1	4_2	5_3	6_4	4_1	5_2	6_3	7_4	Other	Total
June	3	W3548	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	4	W3548	—	1	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	1
	7	W4548	2	1	—	—	—	—	—	1	—	—	—	2	—	—	—	—	—	—	—	3
July	8	W4054	—	1	—	—	1	—	—	—	—	—	—	1	—	—	—	—	—	—	—	1
	9	W4056	—	9	—	—	1	—	—	1	—	—	—	4	2	—	—	1	1	—	—	9
	10	W4058	—	21	—	2	—	1	—	1	—	—	—	6	3	—	—	8	3	—	—	21
	11	W4058	—	16	—	15	18	1	—	4	—	—	—	5	1	—	1	1	2	—	2	16
	12	W4558	1	17	—	1	30	—	—	2	—	—	—	9	2	—	—	2	1	—	2	18
	13*	W5058	—	1	—	6	6	—	—	—	—	—	—	—	—	—	—	1	—	—	—	1
	17	W5056	17	8	6	—	1	—	—	5	—	—	—	13	2	—	1	—	—	—	10	31
	18	W5054	6	4	—	2	16	1	—	2	—	—	2	2	—	—	—	4	—	—	—	10
	19	W5052	5	—	—	36	3	3	—	1	—	—	—	2	2	—	—	—	—	—	—	5
	20	W5050	16	1	—	13	2	—	—	5	—	—	3	7	1	—	—	1	—	—	—	17
	23*	W4050	—	—	—	6	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	24	W4050	—	—	—	8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	25	W4050	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	26	W3550	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Aug.	12	W3050	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	15	W3552	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	16*	W3554																				
	22	W3554	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	23	W4054	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	25	W3550	—	—	—	10	42	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	26	W3048	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Sept.	6*	W4054	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	7	W4054	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	8	W4052	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	9	W4052	—	—	—	1	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	10	W3550	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Date		Age: Chum 2	3	4	5	?	Total	Coho 3_2	4_3	5_2	6_3	Other	Total	Chinook 4_1	4_2	Total
June	3	—	—	—	—	—	—	2	—	—	—	1	3	—	—	—
	4	—	—	—	—	1	1	—	—	—	2	—	2	—	—	—
	7	—	—	1	—	—	1	—	2	—	—	1	3	—	2	2
July	8	1	2	—	—	—	3	2	2	—	—	1	5	—	—	—
	9	11	14	8	—	1	34	6	12	—	—	—	18	—	1	1
	10	—	5	24	2	—	31	3	4	1	—	2	10	—	—	—
	11	1	7	4	—	—	12	5	2	—	—	3	10	—	—	—
	12	—	—	1	—	—	1	6	13	—	—	2	21	—	—	—
	13*	—	—	—	—	—	—	1	—	—	—	—	1	—	—	—
	17	—	24	15	—	3	42	3	4	—	—	1	8	—	—	—
	18	—	11	4	—	—	15	2	2	—	—	3	7	1	—	1
	19	—	6	1	—	—	7	—	2	—	—	—	2	—	—	—
	20	5	3	—	—	—	8	—	—	—	—	—	—	—	—	—
	23*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	24	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	25	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	26	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Aug.	12	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	15	—	—	1	—	—	1	—	—	—	—	—	—	—	—	—
	16*															
	22	3	26	22	—	4	55	7	6	—	—	4	17	—	—	—
	23	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	25	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	26	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Sept.	6*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	7	—	4	2	—	—	6	—	—	—	—	—	—	—	—	—
	8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	10	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

* Day set.

B-5. 1956, Key West II (Canada)

Date		Statistical area	Maturity						Age																											
			Sockeye			Chum			Sockeye														Chum						Coho						Chinook	
			I	*M*	?	*I*	*M*	?	2_1	3_2	4_3	5_4	3_1	4_2	5_3	6_4	4_1	5_2	6_3	7_4	Other	Total	2	3	4	5	?	Total	2_1	3_2	4_3	5_3	?	Total	3_2
May	23	W3554	—	2	3	—	—	—	—	—	—	—	—	3	—	—	—	2	—	—	—	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	28	W3552	10	—	—	10	—	—	—	9	—	—	—	—	—	—	—	—	—	—	1	10	9	1	—	—	—	10	—	—	1	—	—	1	—
	29	W3050	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	1	—
	31	W3048	1	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—
June	18	W3546	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—
	19	W3544	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	20	W3542	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	21	W3042	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	22	W3042	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	26	W3044	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	27	W3046	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
July	12	W4056	—	5	—	—	—	—	—	—	—	—	—	2	1	—	—	1	1	—	—	5	—	—	—	—	—	—	1	3	2	1	—	7	—
	13	W4556	3	4	—	8	—	—	1	2	—	—	—	—	—	—	—	4	—	—	—	7	—	7	1	—	—	8	—	5	4	1	1	11	—
	14	W4554	3	3	—	36	—	—	—	1	1	—	1	1	—	—	—	1	—	—	1	6	—	32	4	—	—	36	—	3	1	—	1	5	—
	15	W4552	7	—	—	10	—	1	—	4	1	—	—	—	—	—	—	—	—	—	2	7	—	8	2	—	1	11	1	1	—	—	1	3	1
	17	W4052	—	10	1	8	—	1	—	—	—	—	—	9	—	—	—	2	—	—	—	11	5	4	—	—	—	9	—	—	—	—	—	—	—
	18	W4054	—	2	—	21	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	2	21	—	—	—	—	21	—	—	—	—	—	—	—
	19	W4052	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	1	—	—	—	—	—	—	—
	20	W3552	—	13	—	3	13	1	—	—	—	—	—	13	—	—	—	—	—	—	—	13	2	10	3	—	2	17	—	2	—	—	1	3	—

B-6. 1956, Celtic (U.S.)

Date		Statistical area	Maturity: Sockeye I	Sockeye M	Sockeye ?	Chum I	Chum M	Chum ?	Age: Sockeye 3_2	4_3	5_4	3_1	4_2	5_3	6_4	4_1	5_2	6_3	7_4	Other	?	Total	Chum 2	3	4	5	6	?	Total
July	13	W4552	No data			97	—	4	2	1	1	—	1	2	—	—	4	—	—	—	2	13	1	88	10	—	—	2	101
	14	W4552	〃	〃		42	—	—	2	—	—	—	4	2	—	—	—	—	—	—	1	9	1	39	2				42
	16	W4550	〃	〃		17	—	16	—	—	—	—	2	—	—	—	3	—	—	—	1	6	1	21	6	—	—	5	33
	17	W4550	〃	〃		89	—	10	2	—	—	—	—	—	—	—	2	—	—	—	4	8	59	27	2	—	—	11	99
	18	W4548	〃	〃		8	—	18	—	—	—	—	—	1	—	—	—	—	—	—	—	1	7	14	3			2	26
	19	W4548	—	—	—	No data																	2	2	—	—	—	—	4
	21	W5048	No data			〃	〃		—	—	—	—	1	—	—	—	—	—	—	—	—	1	12	15	1	—	—	6	34
	22	W5048	〃	〃		66	—	2	3	2	—	—	—	1	—	—	—	—	—	—	1	7	35	26	4			3	68
	23	W5050	〃	〃		74	—	6	3	1	—	—	—	—	—	—	—	—	—	—	1	5	40	31	3	1	—	5	80
	24	W5050	〃	〃		55	—	2	7	6	—	—	2	1	—	—	—	—	—	—	6	22	27	22	5			3	57
	25	W5052	〃	〃		25	1	6	1	2	—	—	1	3	—	—	—	—	—	—	2	9	3	23	1	—	—	5	32
	26	W5052	〃	〃		—	—	27	1	—	—	—	7	5	—	—	1	—	—	—	3	17	—	18	6	—	—	3	27
	31	W4558	〃	〃		39	3	2	—	—	—	—	1	1	—	—	1	—	—	—	2	5	37	3	3	—	—	1	44
Aug.	1	W4558	〃	〃		11	12	2	—	—	—	1	1	2	—	—	1	1	—	—	—	6	2	9	12	—	—	2	25
	2	W4556	〃	〃		46	—						2	1				1	—	—		4	43	3	—			—	46
	3	W4556	〃	〃		32	2	17	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5	33	11	—	—	2	51
	4	W4554	〃	〃		24	2	1	—	—	—	—	2	—	—	—	—	1	—	—	—	3	5	17	1			4	27
	5	W4554	〃	〃		19	1	7	—	—	—	—	8	4	—	—	—	—	—	—	3	15	1	19	2	—	—	5	27
	7	W5054	〃	〃		55	—	9	5	—	—	—	13	6	—	—	—	—	—	—	6	30	9	49	3			3	64
	8	W5054	〃	〃		—	—	27	—	—	—	—	6	2	—	—	1	—	—	—	4	13	4	19	—	—	—	4	27
	9	W5556	〃	〃		8	—	1	—	—	—	—	8	1	—	—	—	1	—	—	—	10	6	2	1	—	—	—	9
	10	W5056	〃	〃		14	—	5	—	—	—	—	3	—	1	—	1	1	—	—	1	7	9	7	—			3	19
	11	W5058	〃	〃		4	3	3	—	—	—	—	2	3	—	—	1	—	1	—	2	9	2	4	2			2	10
	17	W5554	〃	〃		68	10	4	—	—	—	—	1	—	—	—	1	—	—	—	—	2	14	49	16	—	—	3	82
	18	W5554	〃	〃		—	—	35	3	3	—	—	22	20	—	—	1	—	—	—	9	58	18	12	4	—	—	1	35
	19	W5552	〃	〃		23	1	16	13	5	1	—	47	22	—	—	1	2	—	—	19	110	10	14	3			13	40
	20	W5552	〃	〃		2	—	1	3	1	—	—	28	6	1	—	—	—	—	—	6	45	—	1	1			1	3
	21	W5552	〃	〃		10	1	1	2	—	—	—	19	10	—	—	—	—	—	—	3	34	—	10	1	—	—	1	12
	22	W5550	〃	〃		36	1	2	13	7	—	—	6	5	—	—	—	—	—	—	5	36	9	15	3	—	—	12	39
	23	W5550	〃	〃		—	—	33	11	1	—	—	2	2	—	—	—	—	—	—	2	18	23	8	1	—	—	1	33
	26	W5548	〃	〃		9	—	9	—	—	—	—	—	—	—	—	—	—	—	—	1	1	6	2	1			9	18
	28	W5548																											
	30	W5048																											
	31	W5048																											
Sept.	1	W5050	—	—	—	6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	3	1	—	—	—	6
	2	W5050	No data			18	—	12	—	3	—	—	—	—	—	—	—	—	—	—	—	3	25	3	—	—	—	2	30
	3	W5052	〃	〃		45	2	4	9	4	—	—	1	1	—	—	—	—	—	—	1	16	26	19	3			3	51
	4	W5052	〃	〃		38	2	5	4	—	2	—	22	10	—	—	—	—	—	—	6	44	4	29	5	—	—	7	45
	12	W4552	〃	〃		11	—	1	1	1	—	—	—	—	—	—	—	—	—	—	—	2	1	10	—	—	—	1	12
	13	W4552					—	—																					
	14	W4550					—	—																					
	15	W4550					—	—																					
	17	W4052					—	—																					
	18	W4050					—	—																					
	19	W4050					—	—																					

Date		Statistical area	Maturity: Sockeye I	Sockeye M	Sockeye ?	Chum I	Chum M	Chum ?	Age: Sockeye 3_2	4_3	5_4	3_1	4_2	5_3	6_4	4_1	5_2	6_3	7_4	Other	?	Total	Chum 2	3	4	5	6	?	Total
May	17	W3048	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—	—	—	—	—	—
	22	W4548	5	—	4	—	—	7	1	—	—	—	4	—	—	—	—	—	—	—	4	9	—	1	3	—	—	3	7
	25	W5046	5	2	2	—	—	5	3	—	—	—	1	1	—	—	2	—	—	—	2	9	—	—	1	4	—	—	5
	28	W6050	2	1	3	—	—	—	—	—	—	—	2	1	—	—	—	—	—	—	3	6	—	—	—	—	—	—	—
June	15	E 7550	1	10	5	7	8	30	—	1	—	—	6	2	—	—	—	2	—	—	5	16	—	4	22	18	1	—	45
	16	E 7550	49	16	26	12	3	27	7	8	—	—	13	23	1	—	6	6	2	—	25	91	—	26	9	6	—	1	42
	19	E 7542	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	22	E 7542	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	26	8050	—	—	12	—	—	3	—	—	—	—	—	—	—	—	—	—	—	—	12	12	1	—	1	1	—	—	3
July	6	8052	—	5	3	4	—	5	—	—	—	—	2	1	—	—	—	2	—	—	3	8	2	6	1	—	—	—	9
	7	8054	—	1	21	33	3	6	—	—	—	—	1	—	—	—	—	—	—	—	21	22	13	18	9	1	—	1	42
	8	8054	2	—	11	79	—	51	—	1	—	—	1	—	—	—	—	1	—	—	10	13	69	53	3	4	—	1	130
	9	8056	—	—	7	60	—	28	—	—	—	—	—	—	—	—	—	—	—	—	7	7	60	12	3	1	—	12	88
	10	8056	—	—	6	9	—	12	—	—	—	—	—	—	—	—	—	—	—	—	6	6	11	7	1	2	—	—	21
	11	8058	3	3	2	44	2	24	—	2	—	—	1	2	—	—	—	—	1	—	2	8	9	40	12	7	—	2	70
	13	W7560	—	—	3	1	1	8	—	—	—	—	—	—	—	—	—	—	—	—	3	3	—	—	—	10	—	—	10
	14	W7558	—	—	—	—	—	8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6	—	2	8
	15	W7558	—	—	14	54	2	29	—	—	—	—	—	—	—	—	—	—	—	—	14	14	30	29	6	9	—	11	85
	17	W7556	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Aug.	3	W7554	—	—	9	—	—	5	—	—	—	—	—	—	—	—	—	—	—	—	9	9	—	—	2	2	—	1	5
	4	W7552	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	5	W7552	—	—	2	32	1	3	—	—	—	—	—	—	—	—	—	—	—	—	2	2	3	24	7	2	—	—	36
	8	W7550	55	1	31	—	—	29	1	4	1	—	29	17	2	—	1	—	—	—	32	87	2	13	8	6	—	—	29
	9	W7548	2	—	3	15	2	41	—	—	—	—	3	—	—	—	—	—	—	—	2	5	3	34	14	3	—	4	58
	10	W7548	—	—	1	—	—	10	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	4	4	—	—	2	10
	11	W7548	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	12	W7546	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	14	8046	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	15	8048	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	16	8048	—	—	—	—	—	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4	—	—	—	4
	17	8050	—	—	—	18	—	32	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	42	6	1	—	—	50
	23	8050	86	1	76	—	—	27	22	23	1	—	22	—	1	—	2	—	—	—	92	163	3	11	7	3	—	3	27
	25	E 7550	164	—	71	68	3	17	8	18	1	—	73	50	3	—	1	—	—	—	81	235	—	28	24	18	1	17	88
	26	E 7550	11	—	2	—	—	27	—	—	—	—	5	5	—	—	1	—	—	—	2	13	—	14	7	5	—	1	27
	27	E 7548	—	—	—	—	—	21	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	12	8	—	—	1	21
	28	E 7548	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Sept.	2	8046			—				—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		—	—	—	—	—
	3	8048	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	4	8048	—	—	—	—	—	8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	2	3	—	2	8
	5	8050	—	—	—	20	5	7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	7	12	9	—	4	32
	16	W6054	—	—	1	—	—	7	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—	1	1	1	4	7

B-8. 1956, PARAGON (U.S.)

Date		Statistical area	Maturity: Sockeye I	Sockeye M	Sockeye ?	Chum I	Chum M	Chum ?	Age: Sockeye 3_2	4_3	5_4	3_1	4_2	5_3	6_4	4_1	5_2	6_3	7_4	Other	?	Total	Chum 2	3	4	5	6	?	Total
July	12	W4058	No data				–	18	–		–		2	3	–		3	1		–	2	11		4	14		–		18
	13*	W4558	"	"		99	37	1	—	—	—	—	—	3	1	—	6	1	—	—	1	12		80	55	2	–		137
	15	W5058	"	"		—	—	—	—	—	—	—	—	—	—	—	2	–	–	–	–	2		–					
	20	W5554	"	"		78	6	7	5	4	—	—	16	8	—	—	10	–	–	–	3	46	-	59	30	-		2	91
	21	W5554	"	"		33	9	2	2	2	—	—	17	8	—	—	4	5	—	—	6	44	—	15	29	-			44
	22	W5552	"	"		–		8		–		1	8	3	–	–		–		–	1	13	—	6	2				8
	23	W5552	"	"		—	—	19	3	2	—	—	8	5	2	1	3	—	—	—	2	26	-	14	4	-		1	19
	24	W4550	"	"		—	—	10	12	1	—	—	14	6	–	-	—	–		-	4	37	1	5	4			–	10
	25	W5550	"	"		—	—	29	1	—	—	—	2	–	–		–	–	–			3	9	17	3		-		29
	26	W5548	"	"		15	—	18	1	–		—	–				–		–		1	2	18	11	4				33
	27	W5548	"	"		—	—	1	2	—	—	—	—	—	—	—	—	—	—	—		2	1			–			1
	28	W5546	"	"		—	—	—	—	—	—	—	—	—	—	—	—	—	—	–			—	-		–	-	–	
	29	W5544	"	"		–		-		—				–			–		–				–		–	–		-	
	31	W6544	"	"		—	—	—	—	—	—	—	—	-	—		–		–	—					—				
Aug.	1	W6046	"	"		—	—	—	—	—	—	—	—	—	—	—	—	—	—	–		–	-	-		–	-	-	-
	2	W6048	"	"		—	—	5	—	—	—	—	—	—	—	—	—	—	—	—	—		—	—	2	3	–	–		5
	3	W6048	"	"		—	—	27	1	1	—	—	—	—	—	—	—	—	—	—	—	2	—	18	8	1	-		27
	4	W6050	"	"		—	—	28	1	—	—	—	6	3	—	—	—	—	—	—	—	10	1	16	11		-		28
	5	W6550	"	"		31	—	1	1	1	—	1	1	1	—	—	—	—	—	—	2	7	3	24	5				32
	6	W6050	"	"		—	—	33	1	—	—	—	9	4	—	—	—	—	—	—	—	14	—	22	9	—	-	2	33
	7	W6052	"	"		—	—	10	—	—	—	—	12	9	—	—	—	—	—	—	2	23	—	6	3	1			10
	8	W6054	"	"		62	16	2	2	—	—	—	6	6	—	—	1	4	—	—	2	21	—	57	23				80
	19	W7052	"	"		—	—	5	17	6	—	—	2	—	—	—	—	—	—	—	1	26	1	3	1			-	5
	20	W7050	"	"		—	—	21	3	4	—	—	3	10	—	—	2	—	—	—	1	23	—	12	9	—			21
	21	W7050	"	"		—	—	40	1	7	—	—	3	—	—	—	—	—	—	—	—	11	1	18	19	1	-	1	40
	22*	W7048	"	"		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—			–	-	-				
	22	W7048	"	"		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—			–	-	—				
	25*	W7046	"	"		—	—	—	—	—	—	—	—			-		—					–					-	-
	27	W6546	"	"		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—						—	-	-	-
	28	W6546	"	"		—	—	—	—	—	—		—	–		—		—		–				-	–	-			
	29	W6548	"	"		—	—	—	—	—	—	—	—	—	—	—	—	–		–			–	-					
	30	W6548	"	"		—	—	7	—	—	—	—	—	—	—	—	—	—	—	—	—		—	5	2				7
	31	W6550	"	"		37	3	11	—	1	—	—	—	2	—	—	1	—	—	—	—	4	2	35	13			1	51
Sept.	2	W6552	"	"		24	—	7	4	3	—	—	8	9	—	—	—	—	—	—	—	24	6	23	2	-		-	31
	3	W6552	"	"		—	—	17	—	1	—	—	5	3	—	—	1	2	—	—	2	14	3	8	6				17
	7	W6552	"	"		—	—	4	—	—	—	—	—	—	—	—	1	—	—	—	1	2	—	4					4
	8	W6552	"	"		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—					-
	10	W6550	"	"		—	—	16	—	—	—	—	3	1	—	—	—	—	—	—	1	5	1	11	4				16
	11	W6550	"	"		—	—	10	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	8	2		-		10
	12	W6548	"	"		—	—	20	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5	15	-			20
	14	W6048	"	"		—	—	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	2				4
	15a	W5548	"	"		—	—	-			-																		
	17	W5048	"	"		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		-			
	22	W3548	"	"		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	24	W3050	"	"																									

* Day set

Date		Statistical area	Maturity: Sockeye I	Sockeye M	Sockeye ?	Chum I	Chum M	Chum ?	Age: Sockeye 3_2	4_3	5_4	3_1	4_2	5_3	6_4	4_1	5_2	6_3	7_4	Other	?	Total	Chum 2	3	4	5	6	?	Total
May	25	W5058	No data			—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	2	2	—	—	—	1	—	—	1
	31	W6552	"	"		—	33	1	—	—	—	—	—	—	—	—	—	—	—	—	39	39	—	—	15	18	—	1	34
June	7	W6554	"	"				17	—	—	—	—	—	—	—	—	—	—	—	—	62	62	—	—	6	10	—	1	17
	8	W6556	"	"		—	—	15	—	—	—	—	—	—	—	—	—	—	—	—	2	2	—	—	6	9	—	—	15
	9	W6556	"	"		—	—	14	—	—	—	—	—	—	—	—	—	—	—	—	2	2	—	—	12	2	—	—	14
	10*	W6056	"	"		—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	1
	11	W6056	"	"		—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	3	3	—	—	—	1	—	—	1
	13	W6558	"	"		—	34	11	—	—	—	—	—	—	—	—	—	—	—	—	2	2	—	—	36	9	—	—	45
	14	W6558	"	"		—	64	62	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—	83	43	—	—	126
	16	W7060	"	"		—	—	19	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—	10	9	—	—	19
	17	W7058	"	"		—	56	1	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—	34	23	—	—	57
	18	W7058	"	"		—	31	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—	20	11	—	—	31
	20	W7056	—	293	624	—	—	62	—	—	—	—	162	74	—	—	31	22	1	1	626	917	—	—	28	7	—	27	62
	21	W7054	No data			3	26	38		—	—	—	—	—	—	—	—	—	—	—	679	679	—	—	42	21	—	4	67
	25	W7054	"	"		—	—	19	—	—	—	—	—	—	—	—	—	—	—	—	83	83	—	—	5	3	—	11	19
July	29	W7054	"	"		—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—	2	—	—	—	2
	30	W7554	"	"		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—	—	—	—	—	—
	31	W7554	"	"		—	—	9	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—	5	1	—	3	9
Aug.	2	W7058	"	"		—	—	5	—	—	—	—	—	—	—	—	—	—	—	—	4	4	—	—	3	2	—	—	5
	3	W7058	"	"		11	—	20	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3	14	14	—	—	31
	4	W7058	"	"		—	—	6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5	1	—	—	6
	5	W7058	"	"		—	—	11	—	—	—	—	—	—	—	—	1	—	1	—	—	2	—	1	10	—	—	—	11
	6	W7058	"	"			—	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4	—	—	—	4
	7	W7056	"	"		—	—	11	—	—	—	—	—	1	—	—	—	—	—	—	—	1	—	—	10	—	—	1	11
	8	W6558	"	"			—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	9	W6058	"	"		—	—	1	—	—	—	—	—	—	—	—	—	1	—	—	—	1	—	—	1	—	—	—	1
	11	W6556	"	"				—	—	1	—		1	—	—	—	—	—	—	—	—	2	—	—	—				
	12	W6556	"	"		—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—			1	—	—	—	1
	13	W6556	"	"		—	—	3	—	—	—	—	—	1	—	—	—	—	—	—	—	1	—	1	1	—	—	1	3
	14	W6556	"	"		—	—	6	—	—	—	—	—	—	—	—	—	—	—	—	11	11	—	1	4	—	—	1	6
Sept.	12	W7054	"	"			—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	14	W7054	"	"		—	—	12	—	—	—	—	1	—	—	—	—	—	—	—	—	1	—	4	6	1	—	1	12
	15	W7554	"	"					—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	16	W7056	"	"					—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	17	W7058	"	"					—	—	—	—	—	—	—	—	—	1	—	—	—	1	—	—	—	—	—	—	—
	19	W6556	"	"					—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	21	W7054	"	"		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

* Day set.

B-10. 1957, Fort Ross (Canada)

Date		Statistical area	Maturity: Sockeye I	Sockeye M	Sockeye ?	Chum I	Chum M	Chum ?	Age: Sockeye 2_1	3_2	4_3	5_4	3_1	4_2	5_3	6_4	4_1	5_2	6_3	7_4	?	Total
May	19	W3554	—	3	—	—	5	—	—	—	—	—	—	1	—	—	—	2	—	—	—	3
	20*	W3552		—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	21	W3552	—																			
	22*	W3554	—	1	—	—	1	—	—	—	—	—	—	—	—	—	—	1	—	—	—	1
	23	W3554	—	2	—	1	7	50	—	—	—	—	—	—	—	—	—	—	1	—	1	2
June	8	W3550	2	20	9	35	3	8	—	1	—	—	—	27	—	—	—	1	—	—	2	31
	9*	W3550	—	—	—	—	—															
	9	W3550	2	45	7	25	6	5	—	1	—	—	—	44	1	—	—	6	—	—	2	54
	10	W3550	1	48	14	26	4	2	—	—	—	—	—	45	—	—	—	4	—	—	14	63
	14	W4550	22	11	5	9	1	2	—	27	2	—	—	8	—	—	—	—	—	—	1	38
	21	W5550	7	1	3	7		—	—	3		—	—	4	1		—	—			3	11
	22*	W5550																				
	22	W5550	4	—	—	6	—	—	—	2	—	—	—	1	—	—	—	—	—	—	1	4
	23	W5550	57	1	8	8	—	3	—	22	31	—	—	9	1	—	—	1	—	—	2	66
	24	W5550	1	1										1							1	2
	28	W4550	5	—	2	13	—	1	—	5	—	—	—	1	—	—	—	—	—	—	1	7
	30	W4550	2	6	—	25	—	9	—	1	1	—	—	5	—	—	—	—	—	—	1	8
July	2	W4050	2	30	4	2	—	—	—	3	—	—	—	29	3	—	1	—	—	—	—	36
	3	W3550	—	18	2	13	—	—	—	—	—	—	—	19	—	—	—	1	—	—	—	20
	20	W3550	—	120	—	—	—	—	—	17	—	—	—	94	3	—	—	2	—	—	4	120
	21	W3550	—	7	—	—	—	—	—	2	—	—	—	5	—	—	—	—	—	—	—	7
	24	W4550																				
	26	W4550	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	28	W5550	2	—	—	6	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	2
	29	W5550	2	—	—	3	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	2
	30	W5552	17	2	3	2	—	—	1	14	2	—	—	5	—	—	—	—	—	—	—	22
	31	W5552	9	—	—	16	—	—	—	6	1	—	—	1	1	—	—	—	—	—	—	9
Aug.	2	W4552	—	—	—	11	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	4	W4552	—	3	—	13	—	1	—	1	—	—	—	2	—	—	—	—	—	—	—	3
	6	W3552				4	1															
	7	W3552																				
	8	W3552					2															
	18	W3552																				
	19	W4050																				
	22	W4050																				
	25	W3548																				
	26	W3548																				
	27	W3548																				
	28	W3048																				

Date		Age: Chum 2	3	4	5	?	Total	Coho 2_1	3_2	4_3	5_4	3_1	4_2	?	Total
May	19	—	—	5	—	—	5	—	—	—	—	—	—	—	—
	20*	—	—	1	—	—	1	—	1	—	—	—	—	—	1
	21														
	22*	—	—	1	—	—	1	—	—	—	—	—	—	—	—
	23	—	11	45	1	1	58	—	2	—	—	—	—	—	2
June	8	19	18	1	—	8	46	2	87	5	1	2	—	18	115
	9*														
	9	15	11	—	—	10	36	1	36	1	—	—	1	11	50
	10	15	9	1	—	7	32	—	17	1	—	—	1	4	23
	14	3	9	—	—	—	12	—	14	8	—	—	—	2	24
	21	—	3	4	—	—	7	—	1		—		—		1
	22*														
	22	2	4	2	—	—	6	—	2	—	—	—	—	—	2
	23	2	7	2	—	—	11	—	8	—	—	—	—	—	8
	24								2						2
	28	10	3	—	—	1	14	—	1	—	—	—	—	1	2
	30	25	6	—	—	3	34	—	17	—	—	—	—	—	17
July	2	1	1	—	—	—	2	—	—	—	—	—	—	—	—
	3	1	10	2	—	—	13	—	—	—	—	—	—	—	—
	20	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	21	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	24														
	26	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	28	2	4	—	—	—	6	—	—	—	—	—	—	—	—
	29	1	2	—	—	—	3	—	—	—	—	—	—	—	—
	30	1	—	—	—	1	2	—	—	—	—	—	—	—	—
	31	11	4	1	—	—	16	—	—	—	—	—	—	—	—
Aug.	2	10	1	—	—	—	11	—	—	—	—	—	—	—	—
	4	11	2	—	—	1	14	—	—	—	—	—	—	1	1
	6			5	—	—	5	—	1	—	—	—	—	—	1
	7														
	8		1	1			2								
	18														
	19														
	22														
	25														
	26														
	27														
	28														

* Day set.

Date		Statistical area	Maturity: Sockeye I	Sockeye M	Sockeye ?	Chum I	Chum M	Chum ?	Age: Sockeye 2_1	3_2	4_3	5_4	3_1	4_2	5_3	6_4	4_1	5_2	6_3	7_4	?	Total
May	13	W3046				—	—		—	—	—	—	—	—	—	—	—	—	—	—	—	—
	14*	W3046			—																	
	15	W3046	—			1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	16	W3544	—		—			—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	17	W3542	—	—									—	—	—	—	—	—	—	—	—	—
	18	W3544																				
	26	W3544	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	27	W4044					—		—	—												
	28	W4046		—		1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	29	W3548	—	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—
	30	W3548		—			—				—	—										
June	14	W3554	—	19	1	8	140	61	—		—		—	6	3	—	2	8	—	—	1	20
	15	W3554	1	34	3	18	178	157	—	1	—	—	1	9	9	—	2	14	—	—	2	38
	29	W4554	5	6	—	63	—	17	—	—	—	—	1	8	1	—	1	—	—	—	—	11
July	1	W5554	14	16	9	18	4	2	—	—	1	—	1	23	4	—	1	9	—	—	—	39
	3	W5554	45	29	51	58	6	—	—	14	7	—	1	72	14	—	—	13	—	—	4	125
	8	W4558	4	54	1	18	2	1	—	1	—	—	—	29	5	—	1	23	—	—	1	59
	9	W4558	2	14	2	69	2	—	—	—	—	—	—	14	1	—	—	2	—	—	1	18
	9*	W4558	—			—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	10	W4558	4	32	—	32	8	—	—	—	2	—	—	13	9	—	—	12	—	—	—	36
	11*	W4554			—																	
	12	W4554	6	4	—	22	2	1	—	3	1	1	—	4	1	—	—	—	—	—	—	10
	31	W3554	—	16	1	—	1	2	—	2	—	—	—	12	1	—	—	2	—	—	—	17
Aug.	1	W3554		15	—	—	3	—	—	4	—	—	—	9	—	—	—	2	—	—	—	15
	3	W4554	—	1	—	14	1	1	—	1	—	—	—	—	—	—	—	—	—	—	—	1
	8	W3554		2	—	—	—	—	—	1	—	—	—	1	—	—	—	—	—	—	—	2
	16	W4554	2	—	—	16	3	—	—	—	—	—	—	2	—	—	—	—	—	—	—	2
	18	W5554	9	—	2	64	5	2	—	6	1	—	—	4	—	—	—	—	—	—	—	11
	19	W5554	15	—	1	124	3	6	—	9	—	—	—	6	—	—	—	—	—	—	1	16
	22	W4558	2			115	13							2		—			—		—	2

Date		Age: Chum 2	3	4	5	?	Total	Coho 2_1	3_2	3_1	?	Total	Chinook ?
May	13	—	—	—	—	—	—	—	1	—	1	2	1
	14*												
	15	1	—	—	—	1	1	—	—	—			—
	16	—	—	—	—	—							
	17												
	18												
	26	—	—	—	—	—	—	—	1	—	—	1	—
	27	—	—	—	—			—	—	—	—		
	28	1	—	—	—	—	1						—
	29	—	1	—	—	—	1	—	—	—			
	30	—				—							
June	14	—	44	125	8	32	209	3	18	1		22	—
	15	—	126	195	4	28	353	1	23	1	—	25	—
	29	—	71	8	—	1	80	1	16	—	—	17	1
July	1	—	6	12	3	3	24	—	2	—	—	2	
	3	—	35	25	3	1	64	—	1	—	—	1	—
	8	1	18	1	—	1	21	—	—	—		—	—
	9	4	62	4	—	1	71	—	12	—	—	12	—
	9*	—	—	1	—	—	1	—	—	—			
	10	1	26	6	—	7	40	—	8	—	—	8	
	11*												
	12	3	19	3	—	—	25	—	1	—	4	5	
	31	—	2	1	—	—	3	—	2	—	—	2	
Aug.	1	—	1	2	—	—	3	—	3	—	—	3	—
	3	5	9	1	—	1	16	—	—	—		—	—
	8		—	—	—	—	—	—	—			—	—
	16	4	12	3	—	—	19	—	—		—	—	
	18	55	10	4	—	2	71	—	—		—	—	
	19	84	45	4	—	—	133		—		—		
	22	78	44	5	—	1	128		—		—		

* Day set.

B-12. 1957, Etsuzan-maru (Japan)

Date		Statistical area	Maturity: Sockeye I	Sockeye M	Sockeye ?	Chum I	Chum M	Chum ?	Age: Sockeye 2_1	3_2	4_3	5_4	3_1	4_2	5_3	6_4	4_1	5_2	6_3	7_4	Other	?	Total	Chum 2	3	4	5	6	?	Total
May	21	E 6550	1	16	0	0	13	0	—	—	—	—	—	—	2	—	—	7	7	—	1	—	17	—	—	12	1	—	—	13
	22	E 6550	0	22	1	0	9	0	—	—	—	—	—	—	1	—	—	13	4	1	—	4	23	—	—	5	3	1	—	9
	25	E 6552	0	8	0	0	4	0	—	—	—	—	—	—	—	—	—	2	3	1	2	8	8	—	—	1	3	—	—	4
	26	E 6552	0	23	0	0	7	0	—	—	—	—	—	—	—	—	—	4	14	2	—	3	23	—	—	4	1	2	—	7
	27	E 6550	0	8	0	0	22	0	—	—	—	—	—	1	—	—	—	2	5	—	—	—	8	—	1	9	6	5	1	22
	31	E 6548	1	9	0	0	9	0	—	—	—	—	—	—	1	1	—	2	5	1	—	—	10	—	—	7	2	—	—	9
June	1	E 6550	0	15	0	0	13	0	—	—	—	—	—	—	—	—	—	4	9	—	1	1	15	—	1	12	—	—	—	13
	5	E 7052	0	5	0	0	11	0	—	—	—	—	—	—	1	—	—	1	3	—	—	—	5	—	—	7	2	2	—	11
	7	E 7552	1	9	0	2	0	1	—	—	—	—	—	—	2	—	—	6	2	—	—	—	10	—	1	1	1	—	—	3
	9	8052	0	20	1	6	1	0	—	—	—	—	—	1	8	—	—	7	4	—	—	1	21	—	4	3	—	—	—	7
	11	8052	0	17	0	2	0	0	—	—	—	—	—	1	7	—	—	4	4	—	—	1	17	—	—	2	—	—	—	2
	12	8052	0	33	29	9	3	0	—	—	—	—	—	3	12	—	—	6	8	—	—	33	62	—	3	8	—	—	1	12
	13	8052	4	30	1	6	1	0	—	—	—	—	—	3	15	—	—	6	8	—	—	3	35	—	1	6	—	—	—	7
	15	8054	—	—	132	—	—	1	—	—	—	—	—	—	11	—	—	24	7	—	—	90	132	—	—	—	—	1	—	1
	21	W7054	0	18	4	0	1	0	—	—	—	—	—	6	5	—	—	2	2	—	2	5	22	—	—	1	—	—	—	1
	23	W7054	0	30	43	0	0	0	—	—	—	—	—	1	12	—	—	7	9	—	—	44	73	—						—
	24	W7056	0	39	38	0	5	0	—	—	—	—	—	9	6	—	—	14	8	—	—	40	77	—	—	4	1	—	—	5
July	6	8054	27	0	4	35	2	0	—	1	5	—	—	2	—	—	—	—	1	—	—	22	31	24	5	6	—	—	2	37
	7	E 7556	11	0	0	20	0	0	—	—	5	—	—	3	1	—	—	—	—	—	—	2	11	12	4	3	1	—	—	20
	8	E 7556	9	1	0	34	9	5	—	—	1	—	—	3	4	—	—	—	1	—	—	1	10	10	25	6	1	—	6	48
	9	8056	3	0	0	44	4	5	—	—	—	—	—	—	3	—	—	—	—	—	—	—	3	12	30	3	3	—	5	53
	10	E 7556	3	2	5	28	0	0	—	1	1	—	—	1	—	—	—	1	1	—	—	5	10	19	6	3	—	—	—	28
	13	E 7052	14	4	0	10	4	0	—	—	2	1	—	3	4	3	—	1	2	1	—	1	18	6	4	3	1	—	—	14
	15	E 6052	3	10	2	19	1	0	—	—	—	—	—	1	1	3	—	2	5	—	1	2	15	11	5	4	—	—	—	20
	16	E 6052	2	6	0	13	6	1	—	—	—	1	—	—	2	—	—	1	2	—	—	2	8	5	6	8	1	—	—	20
	17	E 6052	12	11	0	23	2	0	—	—	2	2	—	2	3	6	—	—	7	1	—	—	23	12	5	8	—	—	—	25
	19	E 6052	5	9	0	12	4	0	—	—	2	1	—	1	1	1	—	1	6	—	1	—	14	9	1	4	2	—	—	16
	20	E 6052	15	7	0	5	3	0	—	—	1	—	—	1	8	5	—	1	5	—	—	1	22	2	3	3	—	—	—	8
	21	E 6052	1	7	0	9	0	0	—	—	1	—	—	—	3	1	—	—	3	—	—	—	8	5	2	2	—	—	—	9
	24	E 6050				—	—	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—		4	—	—	—	—	—	4
	25	E 6050	1	5	2	29	0	24	—	—	—	1	—	—	1	3	—	—	—	1	—	2	8	48	3	2	—	—	—	53
	26	E 6050	5	6	1	17	3	0	—	—	2	—	—	—	2	2	—	—	4	—	—	2	12	17	—	2	—	—	1	20
	27	E 6052	3	1	0	20	6	0	—	—	—	—	—	—	—	2	—	—	2	—	—	—	4	17	1	6	1	1	—	26
	28	E 6052	0	10	0	35	0	2	—	—	—	—	—	—	3	1	—	—	4	1	—	1	10	28	8	—	—	—	1	37
	29	E 6052	20	11	0	67	8	2	—	—	1	—	—	3	7	2	—	—	11	3	—	4	31	33	4	11	—	—	29	77
	30	E 6052	20	8	2	33	4	4	—	—	2	1	—	2	12	3	—	—	2	—	—	8	30	14	10	11	1	—	—	41
	31	E 6552	16	3	1	17	3	0	—	—	6	1	—	1	5	4	—	—	—	—	—	3	20	9	6	4	—	—	1	20
Aug.	1	E 6552	14	0	0	10	2	1	—	—	—	—	—	4	7	1	—	—	2	—	—	—	14	10	1	1	—	—	1	13

Date		Statistical area	Maturity: Sockeye I	Sockeye M	Sockeye ?	Chum I	Chum M	Chum ?	Age: Sockeye 2_1	3_2	4_3	5_4	3_1	4_2	5_3	6_4	4_1	5_2	6_3	7_4	Other	?	Total[1]	Chum 2	3	4	5	6	?	Total[1]
May	18	E 6548	2	7	0	0	9	0	—	—	—	—	—	1	1	2	—	1	2	—	—	2	9	—	1	5	1	2	—	9
	19	E 6548	1	29	0	1	13	1	—	—	—	—	—	—	2	4	—	4	14	—	—	6	30	—	1	8	2	2	2	15
	21	E 6548	0	28	0	1	11	0	—	—	1	—	—	1	2	1	—	6	11	1	—	5	28	—	—	6	5	—	1	12
	23	E 6548	—	—	12	—	—	3	—	—	—	—	—	—	—	—	—	—	—	—	—	12	12	—	—	—	—	—	3	3
	24	E 6548	0	12	0	0	6	0	—	—	—	—	—	—	3	—	—	2	4	1	—	2	12	—	—	2	2	1	1	6
	25	E 7048	0	22	0	2	14	0	—	—	—	—	—	—	2	—	—	7	7	1	—	5	22	—	—	12	3	1	—	16
June	1	E 7048	1	8	1	3	8	0	—	—	—	—	—	1	—	—	—	3	2	—	—	4	10	—	—	10	1	—	—	11
	6	E 7548	3	8	0	0	6	2	—	—	—	—	—	—	3	1	—	3	1	—	—	3	11	—	—	6	1	—	1	8
	8	E 7550	0	2	0	1	1	1	—	—	—	—	—	—	1	—	—	—	—	—	—	1	2	—	1	—	1	—	1	3
	10	E 7548	4	0	0	2	1	0	—	2	1	—	—	—	—	—	—	—	—	—	—	1	4	—	3	—	—	—	—	3
	11	E 7550	2	0	0	3	5	0	1	—	1	—	—	—	—	—	—	—	—	—	—	—	2	—	3	5	—	—	—	8
	12	8050	12	0	0	1	0	0	2	5	2	1	—	—	1	1	—	—	—	—	—	—	12	—	1	—	—	—	—	1
	19	W7550	1	4	0	7	1	0	—	—	—	—	—	1	1	2	—	1	—	—	—	—	5	—	3	5	—	—	—	8
	20	W7550	1	1	0	2	2	0	—	—	—	—	—	—	1	—	—	1	—	—	—	—	2	—	3	1	—	—	—	4
	21	W7050	4	4	0	2	5	0	—	—	1	—	—	3	3	—	1	—	—	—	—	—	8	—	2	4	—	1	—	7
	22	W7050	4	2	0	0	1	0	—	—	—	—	—	1	3	—	—	—	—	—	—	2	6	—	1	—	—	—	—	1
	24	W7550	3	3	0	7	2	0	—	—	1	—	—	—	2	—	—	—	2	—	—	1	6	2	5	2	—	—	—	9
	27	8054	0	22	0	8	1	0	—	—	—	—	—	2	6	—	—	7	7	—	—	—	22	—	7	1	1	—	—	9
	28	8054	1	4	0	0	1	0	—	—	—	—	—	1	1	—	—	2	1	—	—	—	5	—	1	—	—	—	—	1
	29	8054	0	9	0	6	3	0	—	—	—	—	—	1	4	—	—	1	3	—	—	—	9	1	3	4	—	—	1	9
July	7	W6556	0	16	0	0	25	0	—	—	—	—	—	2	2	1	—	4	6	—	—	1	16	—	4	16	2	—	3	25
	8	W7056	1	0	0	1	1	0	1	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	2	—	—	—	—	2
	15	E 6558	12	9	0	0	3	0	—	3	1	—	—	2	4	—	—	3	3	—	—	5	21	—	—	2	—	—	1	3
	16	E 6558	21	3	0	18	5	0	—	5	4	4	—	—	7	—	—	1	3	—	—	—	24	12	6	4	—	1	—	23
	19	E 6052	2	16	0	15	4	0	—	—	—	—	—	—	3	2	—	2	8	3	—	—	18	11	1	6	—	—	1	19
	20	E 6052	4	3	0	7	5	0	—	—	1	—	—	—	2	1	—	—	1	—	—	2	7	6	2	4	—	—	—	12
	21	E 6052	9	5	0	7	3	0	—	—	1	1	—	—	4	2	—	1	2	1	—	2	14	4	3	2	1	—	—	10
	24	E 6052	3	7	0	16	3	0	—	—	2	—	—	—	—	1	—	1	3	—	—	3	10	13	3	2	1	—	—	19
	25	E 6052	4	7	0	37	5	0	—	—	—	—	—	1	2	1	—	2	3	—	—	2	11	25	3	7	1	—	6	42
	26	E 6050	0	4	0	23	2	0	—	—	—	—	—	—	—	—	—	—	3	—	1	—	4	20	2	3	—	—	—	25
	27	E 6050	13	10	0	25	5	0	—	1	—	1	—	2	7	4	—	—	2	2	—	4	23	18	2	10	—	—	—	30
	28	E 6052	3	17	0	32	4	0	1	—	—	—	—	—	3	1	—	—	10	3	—	2	20	20	8	8	—	—	—	36
	29	E 6052	2	9	0	29	2	0	—	1	—	—	—	1	2	1	—	—	5	1	—	—	11	18	7	6	—	—	—	31
	30	E 6052	16	3	0	18	2	0	—	—	1	—	—	4	3	3	—	1	2	1	—	4	19	—	—	—	—	—	20	20
	31	E 6552	20	3	0	16	0	0	—	—	7	—	1	2	8	2	—	—	3	—	—	—	23	4	8	4	—	—	—	16
Aug.	2	E 6552	9	2	0	31	11	0	—	—	—	—	—	2	4	1	—	—	1	2	—	1	11	8	10	20	1	—	3	42
	4	E 6552	15	4	0	7	2	0	—	—	—	1	—	3	5	3	—	2	—	—	—	5	19	4	1	3	1	—	—	9
	5	E 6552	32	3	0	16	1	0	—	2	3	1	—	7	15	4	—	1	1	1	—	—	35	6	5	6	—	—	—	17
	6	E 6052	18	9	0	16	4	0	—	—	1	1	—	5	12	3	—	1	3	—	1	—	27	9	5	5	—	—	1	20
	8	E 6052	18	2	0	15	5	0	—	—	2	—	—	4	7	—	—	1	4	1	1	—	20	13	2	3	1	—	1	20

[1] The total number of fish given in this table for operations from July 25 through August 8 is higher than that shown in Appendix Table A. Data in this table are for the total catch of each species without consideration of mesh sizes making the catch. Data in Appendix Table A were based only on fish which were caught in known mesh sizes.

Date		Statistical area	Maturity: Sockeye I	Sockeye M	Sockeye ?	Chum I	Chum M	Chum ?	Age: Sockeye 3_2	4_3	5_4	3_1	4_2	5_3	6_4	4_1	5_2	6_3	7_4	Other	?	Total	Chum 2	3	4	5	6	?	Total
May	28	W7550	3	4	—	19	13	2	—	—	—	—	2	3	—	—	—	1	—	—	1	7	—	—	28	2	2	2	34
	30	W7550	7	—	1	25	34	3	—	1	—	—	—	6	—	—	—	1	—	—	—	8	—	8	47	7	—	—	62
	31	W7550	6	—	—	14	7	—	—	—	—	—	—	4	—	—	1	1	—	—	—	6	—	7	12	2	—	—	21
June	8	W7552	5	47	—	1	—	—	—	—	—	1	—	22	—	—	14	12	—	—	3	52	—	—	1	—	—	—	1
	9	8052	3	53	2	5	5	—	—	1	—	—	5	20	—	—	11	14	—	—	7	58	—	—	8	1	1	—	10
	10	W7552	—	41	26	8	4	2	—	—	—	—	2	38	—	1	8	10	—	—	8	67	—	3	9	2	—	—	14
	15	W7556	3	196	38	—	12	2	—	—	—	—	9	41	—	1	102	65	—	1	18	237	—	1	9	4	—	—	14
	17	W7556	1	150	36	3	13	1	—	—	—	—	4	38	—	—	95	37	—	—	13	187	—	1	14	2	—	—	17
	18	W7056	—	87	30	1	8	—	—	—	—	—	8	33	1	—	42	28	—	—	5	117	—	—	3	6	—	—	9
	19	W7056	—	67	1	—	—	1	—	—	—	—	—	10	—	—	34	19	—	—	5	68	—	—	1	—	—	—	1
	20	W7056	—	9	—	—	1	—	—	—	—	—	—	2	—	—	2	5	—	—	—	9	—	—	1	—	—	—	1
	21	W7056	—	62	1	—	6	—	—	—	—	—	6	20	—	—	23	11	—	—	3	63	—	—	4	2	—	—	6
	22	W7054	—	85	3	1	4	—	—	—	—	—	6	32	—	—	32	10	—	—	8	88	—	—	5	—	—	—	5
	23	W7056	—	19	—	—	1	—	—	—	—	—	3	5	—	—	11	—	—	—	—	19	—	—	—	1	—	—	1
	24	W7054	1	14	—	1	9	—	—	—	—	—	4	3	—	—	6	2	—	—	—	15	—	6	3	1	—	—	10
July	8	W6556	—	—	2	—	—	—	—	—	—	—	—	1	—	—	—	1	—	—	—	2	—	—	—	—	—	—	—
	9	W6556	—	—	1	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—
	10	W6556	—	18	2	2	6	—	—	—	—	—	—	12	—	—	2	6	—	—	—	20	—	3	5	—	—	—	8
	15	W6054	41	11	14	75	6	9	20	6	—	—	16	15	—	—	6	2	—	—	1	66	1	63	20	2	—	4	90
	17	W6052	103	3	3	32	—	6	7	9	—	—	58	27	—	—	4	—	—	—	4	109	2	25	10	1	—	—	38
	19	W6050	5	1	2	87	—	2	1	—	—	—	5	—	—	—	1	—	—	—	1	8	40	43	6	—	—	—	89
	21	W6550	3	—	—	52	2	2	—	1	—	—	2	—	—	—	—	—	—	—	—	3	8	37	11	—	—	—	56
	24	W6552	97	9	17	224	1	28	36	15	—	—	30	24	—	—	1	1	—	—	16	123	25	171	39	1	—	17	253
	25	W6552	—	15	—	34	1	—	—	2	—	—	1	6	—	—	1	4	—	—	1	15	1	16	18	—	—	—	35
	27	W6556	—	3	—	1	1	—	—	—	—	—	—	3	—	—	—	—	—	—	—	3	—	2	—	—	—	—	2
	27*	W6556	—	—	—	6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	3	1	—	—	—	6
	28	W6556	—	1	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	1	—	—	—	—	—	—	—
	30	W6552	7	12	1	36	—	—	2	—	—	—	5	11	1	—	1	—	—	—	—	20	—	32	4	—	—	—	36
	31	W6552	16	10	1	31	1	—	5	2	—	—	13	4	—	1	1	—	—	—	1	27	6	25	1	—	—	—	32
Aug.	9	W6550	16	—	—	158	—	5	1	2	3	—	9	—	—	—	—	—	—	—	1	16	17	121	23	2	—	—	163
	11	W6552	2	—	—	62	1	—	—	—	—	—	2	—	—	—	—	—	—	—	—	2	9	46	6	2	—	—	63
	14	W7054	—	1	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	1	—	—					
	15	W6554	1	4	—			2					2	1		—	1	1				5		1		1			2
	18	W6552	—	—	14	178	10	59	1	3	1	—	3	3	—	—	2	—	—	—	1	14	40	167	36	—	—	4	247
	20	W6550	5	—	1	32	1	3	3	1	—	—	1	—	—	—	—	—	—	—	1	6	—	31	4	—	—	1	36
	21	W6550		2	—	6	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	2		5	1				6
Sept.	8	W4058	—	—	2	4	7	—	—	—	—	—	—	2	—	—	—	—	—	—	—	2	—	7	4	—	—	—	11

Date		Statistical area	Maturity: Sockeye I	Sockeye M	Sockeye ?	Chum I	Chum M	Chum ?	Age: Sockeye 3_2	4_3	5_4	3_1	4_2	5_3	6_4	4_1	5_2	6_3	7_4	Other	?	Total	Chum 2	3	4	5	6	?	Total
July	21	W7550	No data			17	2	—	1	—	—	—	—	1	—	—	—	—	—	—	2	4	—	18	1	—	—	—	19
	22	W7550	〃	〃		54	3	—	1	1	—	—	3	5	—	—	1	1	—	—	2	14	—	48	8	—	—	1	57
	24	W7552	〃	〃		21	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	1	1	14	6	—	—	—	21
	25	W7552	〃	〃		—	—	1	—	—	—	—	—	1	—	—	—	—	—	—	—	1	—	—	—	—	—	1	1
	27	W7554	〃	〃		3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	2	—	—	—	3
	27*	W7556	〃	〃		1	—	1	—	—	—	—	1	—	—	—	—	—	—	—	—	1	—	1	—	—	—	1	2
	28	W7556	〃	〃		3	—	1	—	—	—	—	—	1	1	—	—	—	—	—	—	2	—	3	—	—	—	1	4
	30	W7552	〃	〃		9	1	—	—	—	—	—	—	1	—	—	—	—	—	—	—	1	1	5	4	—	—	—	10
	31	W7552	—	—	—	1	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	1	—	—	—	3
Aug.	1	W7552	No data			3	—	1	—	—	—	—	—	1	—	—	—	—	—	—	—	1	—	4	—	—	—	—	4
	6	8050	〃	〃		67	5	5	9	8	1	—	13	15	—	—	—	—	—	—	4	50	5	53	18	1	—	—	77
	7	8050	104	2	42	4	—	1	31	10	1	1	56	25	—	—	4	5	—	1	14	148	—	3	2	—	—	—	5
	8	W7548	77	—	5	59	2	3	2	1	1	—	49	19	1	—	2	—	—	—	7	82	2	51	10	1	—	—	64
	9	8050	116	—	53	46	—	5	9	12	1	1	72	46	5	—	2	1	—	—	20	169	5	34	8	—	—	4	51
	12	W7552	1	1	—	1	—	—	—	—	—	—	—	1	—	—	—	—	—	—	1	2	—	—	1	—	—	—	1
	13	8054	—	—	—	1	2	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	2	—	—	2	5
	14	W7554	3	—	1	15	1	2	—	1	—	—	1	1	—	—	1	—	—	—	—	4	1	11	4	—	—	2	18
	16	W7552	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1
	17	W7552	4	—	—	76	6	2	—	—	—	—	1	2	—	—	—	—	—	—	1	4	3	45	33	2	1	—	84
	18	8052	1	—	—	39	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	1	—	23	16	—	—	—	39
	20	8050	46	—	35	26	1	—	10	9	2	—	29	16	—	—	—	—	—	—	15	81	—	22	5	—	—	—	27
	21	8050	77	—	8	14	—	—	22	9	—	1	19	20	—	—	—	1	—	—	13	85	—	12	2	—	—	—	14
	22	8050	111	—	8	23	2	5	14	10	—	—	57	19	1	—	2	—	—	—	16	119	—	25	5	—	—	—	30
	23	8050	41	9	3	159	6	10	6	7	—	—	15	21	1	—	1	—	—	—	2	53	7	151	17	—	—	—	175
Sept.	8	W4050	—	—	—		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	10	W4050	—	—	—	—																							
	12	W3050	—	—	—	—	—	—	—												—	—	—			—	—	—	

* Day set.

B-16. 1957, Pioneer (U.S.)

Date		Statistical area	Maturity: Sockeye I	Sockeye M	Sockeye ?	Chum I	Chum M	Chum ?	Age: Sockeye 3_2	4_3	5_4	3_1	4_2	5_3	6_4	4_1	5_2	6_3	7_4	Other	?	Total	Chum 2	3	4	5	6	?	Total
June	10	E 7550	17	25	6	83	11	9	5	2		–		8		–	9	16	1	-	7	48		17	66	16	1	3	103
	11	E 7550	55	9	3	36	3	3	15	20	1		-	4	-		14	8			5	67	–	6	30	2	1	3	42
	12	E 7550	55	10	29	92	9	2	26	23	1	1	8	11	2		6	7	–	1	8	94		23	65	13	1	1	103
	14	E 7552	5	1	25	10	22		–		–		3	6	1		9	9	-		3	31		7	16	7	2		32
	20	E 7552	40	20	3	41	14	1	4	12	1		2	15	-		9	13	-		7	63	-	28	19	5	3	1	56
	22	8052	9	40	7	50	5	-		–		-	6	12			16	9	1	–	12	56	4	44	6	1	–		55
	29	W7556	4	3		43	14				-		–	3	-		2	2	–	—	-	7	–	24	31	2	–	–	57
	30	W7556	4	37	5	43	13	3				-	5	14		–	5	15	–		7	46	1	32	18	4	–	4	59
July	3	W7552	1	–	2	32	-	9	1		-			-	–	—	1			—	1	3	39	1	1	–		-	41
	4	W7552	3	2	1	33	-	8	1		–		–	1	—		–	1	–	—	3	6	38	3	–	–			41
	6	W7550	1	1		67	5	12		–			—		–		1	1	–	—	–	2	49	28	5	2		-	84
	7	W7550	–		—	100	6	5	-	–		—		–		—	-	–	—			53	49	6	–	–	3	111
	8	8050	39	4	5	92	6	48	1	4	–		11	20	2	—	3	–	–	—	7	48	64	74	8	–	–		146
	16	E 7556	–	–	9	37	3	–	2	3	–		–	–	–	–	2	1	–		1	9	34	4	1	-	–	1	40
	19	E 7552		-	5	279	5	28	–	1	-	–		1	1	—	2	–		—	-	5	209	75	10	–	–	18	312
	21	E 7550		1		50	–	–		-	–		–	1		–		-	–		–	1	48	2	–	–	–	–	50
	22	E 7550	-	–	11	40	2	1		3	-	–	5	2		–	1	–		—	–	11	40	2	1	–	–	-	43
	23	E 7552	1	3	–	34	8	4	–		–	-	1	1	—	–	1		–	–	1	4	20	16	9	1			46
	24	E 7552	–	2	–	143	1	48		–		–	–	–		–	1	–	–		1	2	181	11		–	-		192
	25	E 7554	–	–	3	45	–	10	1	-		–		–		–	1	–		-	1	3	40	4	1		–	10	55
	26	E 7554	1	1		38	3	1	–	-	–	-	–		–		2		–	--		2	26	12	4	-			42
	27	E 7556		-	2	90		34	–	1	–		1		–		-	-	–	—	–	2	100	12	11	1	–	-	124
	27*	E 7556			2	4	1	2	–	-		-	–		–	-	1	–	–	—	1	2	4	2	1	–		-	7
	28	E 7556	–		6	58	4	2		–		–		2	–	–	4	--	–		–	6	21	28	14	1			64
	30	E 7552		–		30	4	4	–	–	–		–	-	–	–	–	–	–	–	-	-	18	14	6	–			38
Aug.	8	E 7550	39		2	23	3	3	1	2		1	18	13	1		1	–		—	4	41	–	19	8			2	29
	9	E 7550	4		26	27	1	—	1	1	–	1	14	8	–	-	1	–	–		4	30	2	16	10	–	–	--	28
	11	E 7552	59	2	3	38	6	3	23	19	2	–	5	7	-		2	1		–	5	64	2	30	12	–		3	47
	12	E 7552	84	1	2	96	5	5	15	25	–	–	24	15	1	-	2	1	–		4	87	6	64	34	2		–	106
	13	E 7554	6		-	48		1	—	2	–	–	–	1	-	-	1	2		–		6	18	19	12	–			49
	14	E 7556	41		3	53	—	4	1	6	1	–	9	13	1	–	3	4	–	–	6	44	38	16	3			--	57
	17	E 7552	90	1	26	121	4	2	22	36	1		31	14	—		1	1	–		11	117	18	66	41	1	-	1	127
	18	E 7552	61			79	1	1	17	20	1	1	12	8		–	-	–	–	–	4	61	5	47	27	2		-	81
	19	E 7550			189	53	2	7	7	9	2	2	99	51	1	–	2	1		–	15	189	2	34	22	4		-	62
	20	E 7550	93		3	13	2	2	3	8	–	1	55	23			2	1	–	–	3	96	-	8	9	-	-	-	17
	23	E 7550		-	123	154	4	5	8	18	–		40	42	–	–	2	2			11	123	5	72	83	2	1	-	163
	24	E 7552	14		2	44	3	5	1	5	-	-	2	5	-	–	1	--	–	--	2	16	4	31	12	1		4	52
Sept.	7	W5054	2		2	22	3	6		-		-	2	1	-	–	-	-	-	-	1	4	6	16	8			1	31

* Day set.

B-17. 1958, Fort Ross (Canada)

Date		Statistical area	Maturity: Sockeye I	Sockeye M	Sockeye ?	Chum I	Chum M	Chum ?	Age: Sockeye 2_1	3_2	4_3	5_4	3_1	4_2	5_3	6_4	4_1	5_2	6_3	7_4	6_2	?	Total	Chum 2	3	4	5	?	Total	Coho 3_2	4_3	4_2	?	Total
May	17	W3550	—	3	—	1	—	—	—	—	—	—	—	1	2	—	—	—	—	—	—	—	3	—	1	—	—	—	1	4	—	1	—	5
	19	W3550	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	24	W4550	28	10	1	2	13	—	—	2	1	—	—	25	5	1	—	1	—	—	—	4	39	1	9	4	1	—	15	1	—	—	2	3
	25	W4550	18	18	4	2	24	—	—	—	—	—	2	19	8	1	—	1	1	—	—	8	40	—	15	10	—	1	26	3	1	—	—	4
	27	W4550	56	20	2	12	32	1	—	1	—	—	1	60	13	—	—	—	—	—	—	3	78	—	24	15	3	3	45	—	—	—	—	—
June	7	W5054	—	100	1	—	26	—	—	—	—	—	—	48	13	—	—	25	10	1	—	4	101	—	14	7	2	3	26	—	—	—	—	—
	8	W5054	1	34	2	—	8	—	—	—	1	—	—	16	7	—	—	6	5	—	—	2	37	—	5	2	—	1	8	—	—	—	—	—
	9	W5054	—	34	—	—	25	—	—	—	—	—	—	9	5	—	—	9	4	—	—	7	34	—	10	10	2	3	25	—	—	—	—	—
	10	W5054	—	18	137	—	11	1	—	1	1	—	—	86	12	2	—	39	9	—	—	5	155	—	7	4	1	—	12	—	—	—	—	—
	15	W5554	5	140	1	—	13	—	—	1	3	—	—	74	16	1	—	30	8	—	—	13	146	—	8	1	2	2	13	—	—	—	—	—
	16	W5554	3	32	—	—	2	1	—	1	1	—	—	19	5	1	—	3	1	—	—	4	35	—	3	—	—	—	3	—	—	—	—	—
	23	W5550	14	11	—	7	4	2	—	5	5	—	—	10	2	—	—	—	2	—	—	3	25	—	7	4	—	2	13	—	—	—	—	—
	24	W5550	40	21	—	20	20	1	—	16	6	—	—	32	2	—	—	—	—	1	1	3	61	—	28	10	1	2	41	—	—	—	—	—
	25	W5550	22	14	—	10	4	—	—	12	1	—	—	19	1	—	—	1	—	—	—	2	36	—	9	5	—	—	14	—	—	—	—	—
	26	W5550	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—
July	26	W4550	—	1	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—			—	—	—
Aug.	1	W5550	1	—	—	47	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	1	9	31	2	—	5	47	—	—	—	—	—
	15	W5554	2	1	—	18	7	—	—	—	—	—	—	2	1	—	—	—	—	—	—	—	3	7	15	2	—	1	25	1	—	—	1	2
	18	W4554	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	1	—	—	—	—	—

B-18. 1958, Key West II (Canada)

Date		Statistical area	Maturity: Sockeye I	Sockeye M	Sockeye ?	Chum I	Chum M	Chum ?	Age: Sockeye 2_1	3_2	4_3	5_4	3_1	4_2	5_3	6_4	4_1	5_2	6_3	7_4	?	Total	Chum 2	3	4	5	?	Total	Coho 2_1	3_2	4_3	?	Total
May	11	W3050	1	1	—	—	1	—	—	—	—	—	—	—	1	—	—	—	—	—	1	2	—	—	1	—	—	1	—	1	—	—	1
	17	W3550	—	1	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	1	—	—	—	—	—	—		9	—	—	9
	18	W3550	—	4	1	56	7	—	—	—	—	—	—	2	2	—	—	—	—	—	1	5	3	58	1	—	1	63	—	16	—	5	21
	19	W3550	—	—	1	4	3	1	—	—	—	—	—	1	—	—	—	—	—	—	—	1	—	6	2	—	—	8	—	4	—	—	4
	28	W3050	1	2	—	1	3	—	—	—	1	—	—	1	—	—	—	1	—	—	—	3	1	1	2	—	—	4	—	4	—	2	6
June	1	W4554	2	24	7		14	1						11	8	2	—	3	2	1	6	33	—	3	10		2	15				1	1
	2	W4554	3	21	—	—	4	—	—	—	—	—	—	16	3	2	—	1	1	—	1	24	—	3	1	—	—	4		—	—	—	
	4	W4558	3	94	12	2	27	—	—	—	—	—	—	15	16	7	—	53	13	1	4	109	—	7	13	3	1	24	—	—	—	—	—
	5	W4558	20	107	9	—	19	—	—	1	—	—	—	30	17	5	—	61	16	1	5	136	—	—	15	1	3	19	—	2			2
	13	W3556	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—			—	—								1	—	2	3
	14	W3554	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	1	—						—	—	—	—	
	15	W3554	16	14	—	12	6	—	5	2	—	—	—	6	2	—	—	5	—	—	10	30	11	1	3	—	3	18	2	12	1	8	23
	16	W3554	—	3	—	3	2	—	—	—	—	—	—	3	—	—	—	—	—	—	—	3	2	—	2	—	1	5	1	6	—	2	9
Aug.	16	W3554	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—											
	23	W4558	—	—	—	—	—	—	—	—	—	—	—	—	—	—										—							
	24	W4558																															

B-19. 1958, Attu (U.S.)

Date		Statistical area	Maturity: Sockeye I	Sockeye M	Sockeye ?	Chum I	Chum M	Chum ?	Age: Sockeye 3_2	4_3	5_4	3_1	4_2	5_3	6_4	4_1	5_2	6_3	7_4	Other	?	Total	Chum 2	3	4	5	6	?	Total
May	28	8050	1	9	1	4	2	1	—	1	—	—	—	1	—	—	1	6	1	—	1	11	—	1	3	2	—	1	7
	29	8050	2	7	—	11	25	1	—	—	—	—	1	5	—	—	1	1	—	—	1	9	—	—	25	10	1	1	37
	31	8048	2	5	—	21	24	—	—	—	—	—	1	3	—	—	—	1	—	—	2	7	—	—	35	9	1	—	45
June	1	E 7548	2	1	—	7	10	1	—	—	—	—	—	3	—	—	—	—	—	—	—	3	—	—	9	8	—	1	18
	8	E 7552	3	8	—	18	12	—	—	—	—	—	—	5	—	—	2	4	—	—	—	11	—	2	20	7	1	—	30
	10	8054	1	10	—	1	2	1	—	—	—	—	1	—	1	—	2	3	—	—	4	11	—	—	3	—	—	1	4
	17	W7552	1	49	1	2	35	—	1	1	—	—	10	13	—	—	10	12	—	—	4	51	—	23	12	2	—	—	37
	18	W7052	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	24	W7054	—	2	—	—	2	3	—	—	—	—	1	1	—	—	—	—	—	—	—	2	—	1	1	—	—	3	5
	25	W7054	7	74	3	3	12	—	3	4	—	—	19	33	—	—	7	9	—	—	9	84	2	6	6	1	—	—	15
	26	W7554	1	22	2	8	15	3	—	1	—	—	4	10	—	—	5	2	—	—	3	25	—	16	9	1	—	—	26
	27	W7056	—	2	2	No data			—	—	—	—	—	1	—	—	—	1	—	—	2	4	—	—	—	—	—	1	1
	28	W7056	—	2	—	—	—	—	—	—	—	—	—	1	—	—	—	1	—	—	—	2	—	—	—	—	—	—	—
	30	W7554	—	1	1	1	2	—	—	—	—	—	—	—	—	—	—	1	—	—	1	2	—	3	—	—	—	—	3
July	1	W7052	—	—	—	2	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3	—	—	1	4
	2	W7552	2	5	—	2	—	—	—	—	—	—	—	5	—	—	1	1	—	—	—	7	—	2	—	—	—	—	2
	11	8052	—	—	1	10	1	2	—	—	—	—	—	—	—	—	—	—	—	—	1	1	1	6	4	1	—	1	13
	12	8052	7	6	1	9	1	7	—	4	—	—	1	6	—	—	—	2	—	—	1	14	4	10	—	—	—	3	17
	13	8052	1	—	1	38	3	18	—	—	—	—	—	1	—	—	—	—	—	—	1	2	40	15	1	—	—	3	59
	14	8052	26	—	1	5	305	16	2	16	—	—	1	8	—	—	—	—	—	—	—	27	224	90	9	1	—	2	326
	15	E 7554	16	—	1	49	2	1	5	8	—	—	—	2	—	—	1	—	—	—	1	17	26	20	5	—	—	1	52
	16	E 7554	1	—	—	105	5	2	—	—	—	—	1	—	—	—	—	—	—	—	—	1	83	20	7	1	—	1	112
	17	E 7554	5	1	—	168	2	16	—	2	1	—	1	—	1	—	—	1	—	—	—	6	153	22	2	—	—	9	186
	18	E 7554	15	1	1	120	4	27	1	10	—	—	—	2	—	—	—	2	—	—	2	17	129	13	9	—	—	—	151
	19	E 7554	5	—	—	99	—	26	1	2	—	—	—	2	—	—	—	—	—	—	—	5	112	8	—	—	—	5	125
	20	E 7054	2	—	—	56	9	11	—	—	2	—	—	—	—	—	—	—	—	—	—	2	61	7	6	1	—	1	76
	21	E 7054	2	1	—	59	4	3	—	—	—	—	—	1	—	—	—	1	—	—	1	3	24	37	5	—	—	—	66
	22	E 7052	1	1	—	23	3	2	1	—	—	—	—	—	—	—	—	—	—	—	1	2	1	18	8	—	—	1	28
Aug.	5	W7552	7	1	—	62	—	7	—	4	—	—	—	1	1	—	—	—	1	—	1	8	2	56	10	1	—		69
	6	W7554	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	7	W7554	13	—	1	15	—	1	1	3	—	—	2	6	—	—	—	—	—	—	2	14	—	15	1	—	—	—	16
	10	W7552	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	17	W6552	41	—	1	42	3	20	1	5	—	—	14	18	—	—	1	—	—	—	3	42	10	49	5	—	—	1	65
	18	W6550	30	—	1	12	1	4	2	4	—	—	9	13	1	—	1	—	—	—	1	31	2	15	—	—	—	—	17
	19	W6550	32	—	2	15	3	3	1	—	—	—	12	16	—	—	—	—	—	—	5	34	5	13	3				21
	25	W5052	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—	—	2
	27	W4054	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Date		Statistical area	Maturity: Sockeye I	Sockeye M	Sockeye ?	Chum I	Chum M	Chum ?	Age: Sockeye 3_2	4_3	5_4	3_1	4_2	5_3	6_4	4_1	5_2	6_3	7_4	Other	?	Total	Chum 2	3	4	5	6	?	Total
May	28	8052	—	6	—	—	2	—	—	—	—	—	—	—	—	—	2	3	—	1	—	6	—	—	1	1	—	—	2
	29	E 7552	—	5	1	—	—	—	—	—	—	—	—	—	—	—	—	5	—	—	1	6	—	—	—	—	—	—	—
	31	E 7054	—	5	—	—	3	—	—	—	—	—	—	—	—	—	—	3	1	1		5	—	—	3	—	—	—	3
June	1	E 7054	1	15	2	—	4	—	—	—	—	—	—	1	—	—	4	5	1	2	5	18	—	—	3	1	—	—	4
	2	E 7052	—	12	—	4	23	—	—	—	—	—	—	2	—	1	1	6	—	1	1	12	—	—	19	7	—	1	27
	8	E 7050	3	7	2	9	32	5	—	—	—	—	—	5	—	—	1	3	—	—	3	12	—	1	36	3	1	5	46
	17	8052	—	3	1	32	22	12	—	—	—	—	—	2	—	—	—	—	—	—	2	4	1	10	48	5	—	2	66
	18	8054	—	11	1	34	15	4	—	—	—	—	—	4	—	—	4	3	—	—	1	12	—	6	38	8	—	1	53
	22	E 7554	1	9	—	48	17	7	—	—	—	—	2	2	—	1	2	2	—	—	1	10	—	4	58	1	3	6	72
	30	8050	41	1	2	88	5	6	13	25	—	—	2	—	—	—	—	1	—	—	3	44	79	13	3	2	—	2	99
July	6	8050	32	4	3	42	—	6	2	14	—	—	2	12	—	—	—	4	—	—	5	39	17	24	—	—	—	7	48
	7	W7550	16	1	1	159	1	9	—	5	—	—	4	6	—	—	—	—	—	—	3	18	46	110	5		—	8	169
	8	W7548	5	—	1	12	—	1	1	2	1	—	1	—	—	—	—	—	—	—	1	6	8	5	—	—		—	13
	10	8050	3	2	1	60	5	1	—	—	—	—	—	4	—	—	—	1	—	—	1	6	36	10	7	—	—	13	66
	12	E 7550	44	5	1	17	3	16	9	22	—	—	6	5	—	—	—	2	—	—	6	50	30	—	3	—		3	36
	13	E 7550	10	—	1	16	1	2	—	4	—	—	1	5	—	—	—	—	—	—	1	11	7	8	4	—	—	—	19
	14	E 7548	3	—	1	2	6	4	—	1	—	—	—	2	—	—	—	—	—	—	1	4	6	4	2	—	—	—	12
	15	E 7548	12	—	2	10	1	6	—	3	—	—	4	4	—	—	—	—	—	—	3	14	14	1	1	—	—	1	17
	16	E 7550	14	1	2	15	3	12	1	3	—	—	3	6	—	—	1	1	—	—	2	17	24	1	2	—	—	3	30
	17	E 7550	1	4	2	8	9	1	—	—	—	—	—	4	—	—	—	2	—	—	1	7	1	10	7	—	—	—	18
	18	E 7550	45	5	4	23	7	1	12	23	2	—	3	3	—	—	5	2	—	—	4	54	5	19	3	2	—	2	31
	19	E 7552	2	—	—	131	2	6	1	1	—			—			—		—	—	—	2	117	16	4	—	—	2	139
	20	E 7552	—	—	—	26	5	12		—	—		—		—			—		—		—	20	20	3	—	—	—	43
	21	E 7552	4	—	—	150	2	10	2	1	—	—	1	—		—	—		—	—	—	4	91	59	11		—	1	162
	22	E 7552	1	—	—	8	1	3	—	1			—		—			—	—	—			3	4	4	—		1	12
	24	E 7552	—	—	—	123	2	4								—	—		—		—		35	81	11	—		2	129
	25	8052	—	—	—	136	1	16											—				44	95	9	1	—	4	153
	26	8056	—	—	—	1	2	—			—			—		—		—	—			—		1	2			—	3
	27	8052	4	3	—	74	3	5	—	—	—	—	1	2		—	—	2	—		2	7	4	61	12			5	82
	28	8052	—	—		—																—							
Aug.	5	W7550	64	7	2	17	—	—	22	17	—	—	9	7	2	—	4	2	—		10	73	1	16	—				17
	6	W7550	85	1	2	36	—	1	18	26	—	—	10	24	—	—	1	—	—	—	9	88	3	31	2			1	37
	7	W7548	36	—	1	40	1	3	7	8	—	—	7	10	—	—	2				3	37	2	36	3	—		3	44
	9	W7043	11	—	1	43	1	3	—	—	—	1	7	2	—	—	1	—	—	—	1	12	2	38	3	1		3	47
	10	W7050	32	—	7	78	—	6	—	—	—	—	18	11	—	—	—	1		1	8	39	5	67	8			4	84
	11	W7050	56	1	17	44	—	8	9	7	—	—	10	14	1	—	—				33	74	18	26	—			8	52
	15	W7052	24	5	9	279	6	80	6	6	—	—	6	5	—	—	1	1			13	38	78	194	19			74	365
	19	W6054	—	—	—	5	—	1	—	—	—	—	—	—	—	—							1	4				1	6
	20	W6052	3	2	—	32	—	3	—	—	—	—	2	2	—	—	1					5	10	21	2			3	36
	25	W5048	—	—	—	—																							
	27	W4050	—	—	—	—	—	—	—	—	—	—	—																

B-21. 1959, Fort Ross (Canada)

Date		Statistical area	Maturity: Sockeye I	Sockeye M	Sockeye ?	Chum I	Chum M	Chum ?	Age: Sockeye 2_1	3_2	4_3	5_4	3_1	4_2	5_3	6_4	4_1	5_2	6_3	6_2	?	Total	Chum 2	3	4	5	?	Total
May	17	W4554	—	6	—	—	3	—	—	—	—	—	—	2				3	1	-	-	6	-		2	1		3
	17*	W4554	1	1	—	—	—	—											1	1		2	-					
	18	W4554	2	15	—	—	—	—	—	4	—	—	—	2	1	—	—	8	1		1	17		-				
	18*	W4554		5														2	1	1	1	5						
	19	W4554	3	11	1	—	—	—	—	2	—	—	—	—	3	—	—	8	1		1	15						
	19*	W4554	—	2	—	—	—	—	—	—	—	—	—	1	—	—	—	1		-		2	-	-				
	20	W4554	—	1	—	—	2	—	—	—	—	—	—	—	—	—	—	1	-	-	-	1	-	1	1	—	-	2
	20*	W4554	1	5	—	—	3	—	—	—	—	—	—	1	—	—	—	2	3	-		6	-	—	2	1		3
	21	W4554	3	19	—	4	17	—	—	1	—	—	—	7	4	1	—	7	2	-	-	22	-	9	9	2	1	21
	26	W5054	—	7	—	—	1	—	—	—	—	—	—	2	4	—	—	—			1	7	—	—	1		—	1
	26*	W5054	—	2	—	—	1	—	—	—	—	—	—	—	1				1	-		2		1	-	-	-	1
	27	W5054	—	7	—	—	2	—	—	—	—	—	—	4	1	-		2			-	7	-	1	1			2
	28	W5054	-	7					-			-	-	4	-	-		1	2	-		7	—		-	-		
	28*	W5054	—	—	—	—	1	—	—	—	—	—	—	—						-		—	-	1				1
June	10	W5554	4	9	—	2	2	—	—	—	—	—	—	7	6	—	—	—		—	—	13		1	3		-	4
	11	W5554	2	4	—	—	—	—	—	—	—	—	—	3	2	—	—	1		-	-	6	—	-	-	-		
	12	W5554	3	5	—	—	—	—	—	—	—	—	—	2	2	—	—	3	1	—	—	8						
July	5	W3550	—	6	—	—	—	—	—	—	—	—	—	3	—	—	—	2	-		1	6			-			
	6	W3550	—	2	—	—	—	—	—	—	—	—	—	1	—	—	—	1		-	—	2			-	-	-	-
	7	W3550	—	3	—	—	—	—	—	—	—	—	—	1	—	—	—	2	—	—		3			-			
	10	W3550	—	5	—	—	—	—	—	—	—	—	—	—	1	1	—	2	1	-	-	5	-	-	-		-	
	11	W3550	—	11	—	—	—	—	—	—	—	—	—	6	1	2	—	2	—	-		11						—
	15	W4552	—	6	—	6	1	—	—	—	—	—	—	3	1	—	—	1	1	—		6	3	4			—	7
	18	W4552	—	3	—	1	—	—	—	—	—	—	—	3	—					-		3	1		--	-		1
	19	W4552	—	9	—	2	—	—	—	—	—	—	—	9	-	-	—		—		-	9	-	2	-	—		2
	20	W4552	—	1	—	5	1	—	—	—	—	—	—	1	-	-			-			1		6	-		-	6
	21	W4552	1	1	—	2	3	—	—	1	—	—	—	—	—	—	—	1		-		2	1	4				5
	25	W5554	8	1	1	2	—	—	—	1	4	—	—	3	2	-			—			10	—	2			—	2
	26	W5554	8	3	—	24	3	—	—	4	—	—	—	4	1	1			-		1	11	-	24	- -		3	27
Aug.	1	W5554		3		1						-	-	1	1			--			1	3					1	1
	7	W4052	—	8	2	—	1	—	—	—	—	—	—	7	1	—					2	10			1			1

* Day set.

B-22. 1959, KEY WEST II (Canada)

Date		Statistical area	Maturity						Age																			
			Sockeye			Chum			Sockeye														Chum					
			I	*M*	?	*I*	*M*	?	2_1	3_2	4_3	5_4	3_1	4_2	5_3	6_4	4_1	5_2	6_3	7_4	?	Total	2	3	4	5	?	Total
May	18	W4550	29	15	2	4	10	5	—	6	—	—	—	21	6	—	—	10	1	—	2	46	1	11	3	—	4	19
	19	W4550	35	18	5	3	2	1	—	5	1	—	—	26	9	—	—	8	4	1	4	58	—	5	—	—	1	6
	21	W4554	4	111	15	—	26	4	—	—	—	—	—	36	18	1	—	37	19	3	16	130	—	6	24	—	—	30
	22	W4554	1	22	3	1	5	—	—	1	—	—	—	8	5	1	—	6	3	—	2	26	—	1	5	—	—	6
	23	W4554	5	—	6	—	9	—	—	7	2	—	—	—	—	—	—	—	—	—	2	11	—	4	5	—	—	9
	25	W4558	3	173	14	—	27	—	—	1	—	—	—	63	36	4	—	58	18	31	6	190	—	4	19	3	1	27
	26	W4558	—	13	—	—	3	—	—	—	—	—	—	5	3	—	—	3	2	—	—	13	—	—	2	1	—	3
June	10	W5554	19	77	9	1	25	1	—	7	2	1	—	39	20	1	—	9	6	—	20	105	—	9	12	2	4	27
	12	W5554	15	133	210	2	114	51	—	9	1	—	—	69	36	3	—	13	10	2	215	358	—	65	55	—	47	167
	14	W6052	4	10	—	2	23	2	—	—	2	—	—	1	6	—	—	1	2	—	2	14	—	11	7	—	9	27
	24	W6052	18	20	3	3	7	1	—	9	1	—	—	10	5	2	—	7	7	—	—	41	1	6	3	—	1	11
	25	W6052	73	28	3	15	44	1	—	33	5	—	—	19	23	2	—	10	4	—	8	104	—	42	16	—	2	60
	27	W6050	82	8	1	155	10	74	—	37	16	1	1	16	6	1	—	3	1	—	9	91	—	62	95	4	78	239
	28	W6050	46	3	51	—	—	—	—	32	8	—	—	5	4	—	—	1	—	—	50	100	—	—	—	—	—	—
	29	W5550	161	—	56	98	9	31	—	127	7	—	—	10	5	—	—	—	—	—	68	217	—	75	29	1	33	138
July	17	W3550	—	11	—	—	—	—	—	—	—	—	—	8	1	—	—	2	—	—	—	11	—	—	—	—	—	—
	18	W3550	—	3	1	—	—	—	—	—	—	—	—	1	1	—	—	2	—	—	—	4	—	—	—	—	—	—
	19	W3552	—	8	—	—	—	—	—	—	—	—	—	1	—	—	—	6	—	—	1	8	—	—	—	—	—	—
	24	W3552	—	3	—	—	—	—	—	—	—	—	—	2	—	—	—	1	—	—	—	3	—	—	—	—	—	—
	25	W3550	—	40	—	—	1	—	—	—	—	—	—	27	3	—	—	6	1	—	3	40	—	—	—	—	1	1

Date		Statistical area	Maturity: Sockeye I	Sockeye M	Sockeye ?	Chum I	Chum M	Chum ?	Age: Sockeye 2_1	3_2	4_3	5_4	3_1	4_2	5_3	6_4	4_1	5_2	6_3	7_4	Other	?	Total	Chum 2	3	4	5	6	?	Total
May	25	8050	0	6	2	1	47	8		—	—	—	—	—	1	—	—	3	1	—	—	3	8	—	1	45	2	—	8	56
	26	8050	0	15	8	0	45	13		1	—	—	—	1	7	2	—	3	2	—	—	7	23	—	—	40	5	—	13	58
	27	8050	1	19	3	0	25	3		1	—	—	—	3	9	1	—	3	2	—	—	4	23	—	1	23	1	—	3	28
	28	W7550	1	7	2	0	37	0	—	2	—	—	—	2	5	—	—	1	—	—	—	—	10	—	1	32	4	—	—	37
	29	W7550	1	7	0	0	63	9						2	3	—	—	1	—	—	—	2	8	—	2	52	9	—	9	72
June	1	W7050	1	4	1	0	5	1						3	—	1		—	—			2	6		5				1	6
	3	W7552	9	20	4	0	33	2	—	6	2	—	—	2	9	1	—	2	5	—	—	6	33	—	—	30	3	—	2	35
	4	W7552	30	5	0	1	4	0	—	25	1	—	—	—	3	—	—	—	1	—	—	5	35	—	—	4	—	1	—	5
	5	8052	2	13	0	0	17	0		2	—	—	—	3	7	—	—	1	1	—	—	1	15	—	1	16	—	—	—	17
	8	8052	0	3	0	10	8	0							2	—	—	1	—	—	—	—	3	—	—	18	—	—	—	18
	10	E 7552	1	16	8	2	7	4			—	—	—	5	8	—	—	1	3	—	—	8	25	—	—	7	2	—	4	13
	13	E 7552	0	4	0	1	16	2							2	—	—	1	—	—	—	1	4	—	1	14	2	—	2	19
	15	W7556	2	31	2	0	0	0		1	1			8	14			2	4			5	35							
	16	8056	0	3	0	0	13	0						—	1	—	—	—	1	—	—	1	3	—	—	12	1	—	—	13
	18	8056	0	21	0	0	7	0						8	8	—	—	1	3	—	—	2	22	—	—	7	—	—	—	7
	19	E 7556	3	14	1	0	0	4	—	2	1	—	—	2	6	2	—	2	2	—	—	1	18	—	—	4	—	—	—	4
	20	E 7556	8	8	1	8	18	10	—	5	1	—	—	—	2	1	—	2	5	—	—	1	17	—	—	24	2	—	10	36
	21	E 7556	1	18	1	0	10	0						1	7	3	—	—	8	—	—	1	20	—	—	6	4	—	—	10
	22	E 7056	1	22	0	12	21	8						4	9	1	—	2	7	—	—	—	23	—	1	31	1	—	8	41
July	9	E 4546	0	0	0	0	16	8																	3	12	1	—	8	24
	11	E 5046	0	0	0	0	1	0													—	—	—	—	1	—	—	—	—	1
	14	E 5048	0	0	0	2	4	0																2	—	3	1	—	—	6
	15	E 5048	0	0	0	0	1	2																		1	—	—	2	3
	16	E 5050	0	0	0	1	6	0																2	1	4	—	—	—	7
	17	E 5052	0	0	0	11	12	2																10	2	9	2		2	25
	18	E 5052	1	0	0	51	60	47					1	—	—	—	—	—	—	—	—	—	1	44	11	54	2	—	47	158
	20	E 5052	0	7	2	3	27	15						1	—	—	—	5	2	1	—	—	9	2	1	26	1	—	15	45
	21	E 5052	0	9	0	26	21	7				1	—	1	3	—	—	—	3	1	—	—	9	17	12	16	2	—	7	54
	27	8058	2	0	3	12	0	0	—	—	—	—	—	1	1	—	—	—	—	—	—	3	5	7	5	—	—	—	—	12
	28	E 7558	16	0	2	44	1	20	—	2	1	—	—	5	6	1	—	—	—	—	—	3	18	9	9	17	—	—	30	65
	29	E 7558	9	0	0	43	3	15	—	1	2	—	—	3	2	—	—	—	—	—	—	1	9	11	8	26	1	—	15	61
	30	E 7558	7	0	1	27	1	4						1	5	1	—	1	—	—	—	—	8	9	9	9	1	—	4	32
	31	E 7058	9	0	0	73	8	53			1	—	—	1	4	1	—	—	—	1	—	1	9	33	26	22	—	—	53	134
Aug.	1	E 7058	82	0	1	65	9	16	—	3	12	3	1	10	20	4	—	—	4	—	—	26	83	44	18	11	1	—	16	90
	2	E 7056	38	0	6	22	16	8	—	—	—	—	1	5	18	7	—	1	—	—	—	12	44	5	16	16	1	—	8	46
	3	E 7056	16	0	1	7	1	1		2	—	1	—	7	3	—	—	—	—	—	—	4	17	1	6	1	—	—	1	9
	4	E 7054	3	0	0	3	1	1					—	—	2	—	—	1	—	—	—	—	3	1	1	2	—	—	1	5
	5	E 7054	20	0	1	40	14	10	—	5	6	—	—	4	3	1	—	—	—	—	—	2	21	31	2	21	—	—	10	64
	7	E 6556	14	0	2	15	3	4	—	3	4	—	—	1	3	1	—	—	—	—	—	4	16	3	7	8	—	—	4	22
	8	E 6556	15	0	4	13	2	0	—	3	8	—	—	1	2	1	—	—	—	—	—	4	19	9	2	3	1	—	—	15
	9	E 6558	77	0	10	15	3	0	—	14	39	5	—	5	5	1	1	1	1	—	—	15	87	14	—	4	—	—	—	18
	10	E 6558	18	1	1	10	6	0	1	5	8	—	—	1	3	—	—	—	1	—	—	1	20	7	2	7	—	—	—	16
	11	E 6558	9	0	0	4	15	0	—	1	5	—	—	—	—	—	—	—	—	—	—	3	9	—	2	15	2	—	—	19
	12	E 6558	19	1	4	16	9	0	—	2	11	2	—	—	2	1	—	—	—	1	—	5	24	10	5	10	—	—	—	25
	13	E 6558	27	1	1	14	0	5	—	4	16	—	—	1	4	—	—	—	—	—	—	4	29	3	3	11	—	—	2	19
	14	E 6558	40	1	4	30	0	3	—	6	19	2	—	6	4	2	—	1	—	—	—	5	45	20	9	1	—	—	3	33
	16	E 6556	16	0	6	17	1	6	—	2	9	2	—	1	—	1	—	—	—	—	—	7	22	—	10	8	—	—	6	24
	17	E 6054	10	1	2	0	3	0	—	1	3	1	—	3	2	—	—	—	—	1	—	2	13	—	—	3	—	—	—	3
	18	E 6054	21	0	1	2	4	1	—	—	1	—	1	8	4	3	1	1	—	—	—	3	22	—	2	4	—	—	1	7
	19	E 6054	20	1	0	5	1	2		1	4		3	6	6							1	21	1	5				2	8
	20	E 6554	43	0	4	13	5	2	—	—	1	2	1	15	8	6	2	1	1	—	—	10	47	4	4	10	—	—	2	20
	21	E 6552	55	0	1	18	0	3	—	—	2	—	—	22	19	8	—	2	—	—	—	3	56	—	10	8	—	—	3	21
	22	E 6052	15	0	3	27	2	8	—	—	—	—	2	2	6	1	—	—	—	—	—	7	18	3	12	14	—	—	8	37

Date		Statistical area	Maturity: Sockeye I	Sockeye M	Sockeye ?	Chum I	Chum M	Chum ?	Age: Sockeye 3_2	4_3	5_4	3_1	4_2	5_3	6_4	4_1	5_2	6_3	7_4	Other	?	Total	Chum 2	3	4	5	6	?	Total
April	24	W5556	—	1	—	No data			—	—	—	—	1	—	—	—	—	—	—	—	—	1	—	—	1	—	—	—	1
	27	W5554	—	15	1	—	6	1	—	—	—	—	—	1	—	—	4	9	—	—	2	16	—	—	7	—	—	—	7
May	20	E 7550	1	20	4	14	169	2	—	—	—	—	—	16	—	—	3	4	—	—	2	25	1	1	166	12	—	5	185
	22	E 7550	1	36	4	30	189	189	—	—	—	—	—	13	2	—	2	6	—	—	18	41	—	1	370	22	—	25	418
	23	E 7550	1	16	—	10	27	5	—	—	—	—	2	—	—	—	2	5	—	—	8	17	—	—	33	4	—	5	42
	24	E 7548	7	19	2	71	105	1	—	—	—	—	1	18	2	—	4	3	—	—	—	28	—	5	165	1	—	6	177
	25	E 7548	16	17	2	112	68	308	—	—	—	—	1	24	3	—	—	4	—	—	3	35	—	4	284	2	—	198	488
	27	E 7048	—	25	2	14	21	2	—	—	—	—	—	12	3	—	5	4	—	—	3	27	—	1	35	1	—	—	37
	28	E 7050	—	20	2	4	14	1	—	—	—	—	—	8	—	—	4	6	—	—	4	22	—	—	19	—	—	—	19
June	3	E 7052	1	14	—	1	10	—	—	—	—	—	—	4	—	—	5	5	—	—	1	15	—	—	11	—	—	—	11
	4	E 7052	—	15	1	—	20	—	—	—	—	—	—	4	1	2	2	7	—	—	—	16	—	—	20	—	—	—	20
	5	E 7052	—	35	1	3	22	—	—	—	—	—	1	15	—	—	13	5	—	—	2	36	—	—	21	4	—	—	25
	6	E 7054	—	54	1	—	14	1	—	—	—	—	—	19	—	1	23	9	—	1	2	55	—	—	15	—	—	—	15
	8	E 7054	—	59	4	1	16	1	—	—	—	—	2	21	1	—	14	21	—	—	4	63	—	—	15	1	—	2	18
	13	8052	—	66	2	39	13	4	—	—	—	—	9	47	5	—	2	2	—	—	3	68	—	—	51	—	—	5	56
	22	8052	3	43	6	8	7	1	—	—	—	—	9	21	1	—	7	8	—	—	6	52	—	5	10	—	—	1	16
	23	E 7552	17	61	5	87	37	—	—	—	—	—	13	52	—	—	8	2	—	—	8	83	—	52	68	1	—	3	124
	24	8054	3	17	—	9	13	1	—	—	—	—	3	13	—	—	—	2	—	—	2	20	—	1	21	1	—	—	23
	25	8054	2	54	1	8	7	—	1	—	—	—	6	36	1	—	4	3	1	—	5	57	—	—	14	1	—	—	15
	26	8056	3	125	37	31	6	2	—	—	—	—	21	79	5	—	5	12	—	—	43	165	—	3	35	—	—	1	39
	27	8056	6	116	16	78	21	4	—	1	—	—	18	78	2	—	5	14	—	—	20	138	—	6	90	2	—	5	103
	28	8058	26	17	1	52	53	—	3	3	—	—	6	19	8	—	—	3	—	—	2	44	—	1	95	7	—	2	105
	30	8060	13	16	3	37	79	4	—	—	—	—	2	19	4	—	—	3	1	—	3	32	—	—	112	6	—	2	120
July	4	E 7558	52	9	7	85	39	26	1	—	—	—	7	34	12	—	1	2	1	—	10	68	—	11	111	1	—	27	150
	15	E 7554	16	2	1	87	5	6	—	1	—	—	6	8	1	—	—	1	1	—	1	19	56	23	17	—	—	2	98
	16	E 7554	3	7	—	26	7	1	1	—	—	—	3	3	—	—	2	—	—	—	1	10	17	7	10	—	—	—	34
	19	E 7050	13	10	1	12	7	1	4	1	—	—	4	9	2	—	—	1	—	—	3	24	2	10	7	—	—	1	20
	22	E 7550	47	6	5	4	2	—	7	4	—	—	22	14	1	—	—	—	—	—	10	58	—	3	3	—	—	—	6
	23	E 7550	47	9	1	6	4	1	13	7	—	—	13	18	5	—	—	—	—	—	1	57	2	5	4	—	—	—	11
	27	8050	186	22	267	95	4	65	90	9	2	—	32	59	4	—	—	1	—	—	278	475	26	96	18	1	—	23	164
	28	8050	121	9	45	63	—	3	102	15	1	—	15	13	2	—	—	1	—	—	26	175	7	51	7	—	—	1	66
	29	8050	124	35	348	119	1	77	100	34	7	1	40	70	11	—	6	6	1	—	231	507	7	175	12	—	—	3	197
Aug.	5	W7550	179	5	183	13	—	1	68	17	3	3	64	70	9	—	—	1	—	—	132	367	—	13	1	—	—	—	14
	6	W7550	102	3	253	104	—	11	27	9	—	3	96	101	14	—	1	—	—	—	107	358	—	101	7	—	—	7	115
	7	W7548	28	—	—	73	1	4	15	6	1	—	—	3	1	—	—	—	—	—	2	28	—	64	7	—	—	7	78
	9	W7548	1	—	—	22	—	7	—	—	—	—	1	—	—	—	—	—	—	—	—	1	—	21	1	—	—	7	29
	12	W7548	1	—	—	24	1	2	—	—	—	—	1	—	—	—	—	—	—	—	—	1	—	23	3	—	—	1	27

B-25. 1959, Tordenskjold (U. S.)

Date		Statistical area	Maturity: Sockeye I	Sockeye M	Sockeye ?	Chum I	Chum M	Chum ?	Age: Sockeye 3_2	4_3	5_4	3_1	4_2	5_3	6_4	4_1	5_2	6_3	7_4	Other	?	Total	Chum 2	3	4	5	6	?	Total
May	25	W7052	—	8	—	—	47	11	—	—	—	—	2	5	—	—	—	—	—	—	1	8	—	1	45	1		11	58
	26	W7052	—	1	—	—	36	—	—	—	—	—	1	—	—	—	—	—	—	—	—	1	—	—	35			1	36
	27	W7050	1	51	3	1	10	—	—	—	—	—	9	24	2	—	7	5	1	—	7	55	—	1	10				11
	28	W7550	—	66	12	—	27	4	—	—	—	—	13	33	7	—	5	6	—	—	14	78	—	—	26	1		4	31
June	2	8050	1	73	34	41	62	48	—	1	—	—	12	62	10	—	3	8	—	—	12	108	—	2	124	2		23	151
	3	8048	1	21	1	47	46	1	—	—	—	—	2	9	1	—	2	6	—	—	3	23	—	4	84	1		5	94
	4	8048	8	2	9	46	58	6	1	1	—	—	1	6	1	—	—	—	—	—	9	19	—	6	69	1		34	110
	7	8048	15	4	3	29	15	2	—	—	—	—	2	15	2	—	—	—	—	—	3	22	—	—	25	1		20	46
	12	8050	6	121	123	22	26	7	6	2	—	—	30	107	13	—	12	16	—	—	64	250	—	2	6	1		46	55
	14	8050	—	51	2	10	5	—	—	—	—	—	5	24	4	—	1	16	—	—	3	53	—	—	14			1	15
	15	8050	4	119	168	67	32	18	1	1	—	—	46	137	18	1	21	33	4	—	29	291	—	14	90	4		9	117
	21	W7552	8	29	1	18	20	1	—	1	—	—	2	20	5	—	4	5	—	—	1	38	—	3	33			3	39
	22	8054	—	99	10	29	14	2	—	1	—	—	12	52	3	—	6	34	—	1	—	109	—	3	37			5	45
	23	8054	—	88	8	11	24	3	—	—	—	—	12	60	1	—	3	11	1	—	8	96	—	2	29			7	38
	24	8056	2	91	12	8	15	5	4	2	—	—	10	63	6	—	6	11	—	—	3	105	—	1	26			1	28
	25	W7556	2	108	45	2	7	1	—	—	—	—	12	72	8	1	6	12	1	—	43	155	—	—	10				10
	27	W7058	—	58	1	1	44	2	—	—	—	—	6	38	2	—	1	7	—	—	5	59	—	26	20			1	47
	28	W7058	—	55	14	—	9	2	—	—	—	—	4	44	7	1	3	3	—	—	7	69	—	6	4			1	11
	29	W7556	—	3	2	—	—	—	—	—	—	—	1	1	—	—	—	—	—	—	3	5							
	30	W7054	—	117	85	27	27	9	1	—	—	1	11	114	16	1	3	31	—	—	24	202	—	13	38	1		11	63
July	1	W7554	1	14	2	9	6	3	—	—	—	—	—	11	—	—	—	—	—	—	6	17	—	5	9	1		3	18
	2	W7552	2	18	1	14	14	4	—	—	—	—	3	8	3	—	1	4	1	—	1	21	—	15	17			-	32
	3	W7052	2	13	—	34	12	7	—	—	—	—	2	7	—	—	1	4	—	—	1	15	—	18	34			1	53
	4	W7052	65	8	166	72	9	7	80	19	2	—	48	51	6	—	3	1	—	—	29	239	—	34	41	1		12	88
	5	W7050	42	32	4	56	—	3	2	2	—	—	26	35	2	1	4	4	—	—	2	78	—	43	15			1	59
	11	W6552	86	31	343	139	5	387	40	4	1	2	44	46	5	—	8	11	—	—	299	460	—	201	70			260	531
	12	W6552	142	29	142	22	2	6	38	6	3	1	52	61	6	—	2	3	—	—	141	313	—	22	6			2	30
	13	W6552	92	7	100	32	2	14	11	5	1	—	33	30	2	—	—	3	—	—	114	199	1	26	18			3	48
	15	W6550	26	1	11	143	—	281	1	5	1	—	8	12	1	—	1	—	—	—	9	38	6	190	23			205	424
	16	W6548	5	—	—	97	—	71	—	—	1	—	3	—	1	—	—	—	—	—	—	5	3	140	12			13	168
	17	W7048	3	1	2	46	—	2	—	—	—	1	4	—	—	—	—	—	—	—	1	6	1	40	6			1	48
	19	W6546	—	—	1	63	—	5	—	1	—	—	—	—	—	—	—	—	—	—	—	1	8	50	8				66
	20	W6048	2	1	2	44	—	2	—	—	—	—	2	2	—	—	—	—	—	—	1	5	4	37	3			2	46
	21	W6048	14	3	3	58	1	7	—	—	—	—	3	10	—	—	1	—	—	—	6	20	9	51	1			5	66
	22	W6548	46	3	13	139	1	42	5	2	—	—	18	23	2	—	—	1	—	—	11	62	48	107	3			24	182
	23	W6050	92	6	39	95	1	37	20	6	—	—	46	43	1	—	1	4	—	—	16	137	25	78	4			26	133
	24	W6050	104	12	178	42	—	16	96	31	2	1	47	41	5	—	—	—	—	—	71	294	18	34	1			5	58
	25	W6052	28	9	29	90	13	213	26	5	—	—	2	6	—	—	1	—	—	—	26	66	2	273	11			30	316
	26	W6050	39	10	20	49	8	3	39	13	—	—	2	8	—	—	—	—	—	—	7	69	2	53	2	1		2	60

Date		Statistical area	Maturity: Sockeye I	Sockeye M	Sockeye ?	Chum I	Chum M	Chum ?	Age: Sockeye 2_1	3_2	4_3	5_4	3_1	4_2	5_3	6_4	4_1	5_2	6_3	7_4	Other	?	Total	Chum 2	3	4	5	6	?	Total
May	28	W7548	3	48	0	1	21	0	—	—	—	—	—	17	8	1	1	5	10	2	—	7	51	–		14	7		1	22
	29	W7550	2	68	0	2	35	0	—	—	—	—	—	43	12	—	—	1	5	—	—	9	70	—	—	13	14	—	10	37
	30	W7550	0	18	0	0	8	0	—	—	—	—	—	8	2	—	—	2	2	—	1	3	18			7	–		1	8
	31	8050	1	26	1	0	18	2	—	—	—	—	—	8	2	—	1	2	6	1	—	8	28	–	–	7	11		2	20
June	1	8050	2	14	0	9	24	0	—	—	—	—	—	—	5	—	—	1	7	2	—	1	16			18	12		3	33
	3	E 7550	4	18	2	12	22	2	—	—	—	—	—	3	6	2	—	6	2	—	—	5	24		—	28	3		5	36
	4	E 7050	0	43	0	9	26	1	—	—	—	—	—	3	12	—	—	13	10	2	1	2	43			18	11		7	36
	6	E 6548	0	33	1	0	8	0	—	—	—	—	—	2	14	—	—	7	3	3	—	5	34	–		7	1			8
	7	E 6548	0	7	1	1	5	1	—	—	—	—	—	—	2	—	—	2	1	—	—	3	8			3	3		1	7
	8	E 6550	0	32	0	0	23	0	—	—	—	—	—	—	3	—	1	11	11	1	—	5	32		–	9	13		1	23
	9	E 6552	3	46	0	3	55	0	—	—	—	—	—	4	7	2	—	11	14	3	2	6	49			25	29		4	58
	10	E 6554	1	29	0	6	43	0	—	1	—	—	—	1	—	—	—	6	15	4	—	3	30	–	13	20	11		5	49
	11	E 7052	0	6	0	3	72	0	—	—	—	—	—	1	2	—	—	—	2	—	1	—	6	–	1	42	30		2	75
	12	E 7552	0	30	0	0	4	0	—	—	—	—	—	10	5	—	—	4	7	—	—	4	30	—		2	2			4
	15	W7552	0	77	0	0	11	0	—	—	—	—	—	61	1	—	—	—	9	—	—	6	77			4	6	—	1	11
	16	W7552																												
	17	W7552	1	202	2	0	8	1	—	1	—	—	—	168	14	1	—	4	4	—	—	13	205		–	7	–		2	9
	18	W7052	3	215	30	3	38	6	—	2	—	—	—	160	19	4	—	2	5	1	—	55	248	—	1	35	2		9	47
	19	W7554	12	249	4	1	21	0	—	2	8	1	—	187	22	1	1	7	3	—	—	33	265	—	1	18	—		3	22
	21	W7556	14	76	58	2	4	1	—	1	13	—	—	46	7	—	—	6	9	1	—	65	148	—	—	4	1	—	2	7
	22	8054	5	56	0	6	35	1	—	—	2	—	—	35	5	1	—	3	7	1	—	8	62	—	—	32	10			42
	24	E 7554	2	24	0	10	14	0	—	—	2	—	—	9	2	—	—	2	8	—	—	3	26	—	—	14	9		1	24
	25	E 7556	0	13	0	5	10	0	—	—	—	—	—	4	2	—	—	3	2	—	—	2	13	—	—	12	3			15
	27	E 7056	5	16	1	28	9	0	—	1	3	—	—	—	2	—	—	6	7	2	—	1	22	—	1	25	10		1	37
	28	E 6556	1	9	0	2	19	2	—	—	1	—	—	—	2	—	—	1	4	2	—	—	10	—	—	14	7	–	2	23
	29	E 6554	2	5	6	10	2	1	—	—	—	—	—	1	2	—	—	—	3	—	—	7	13	—	—	9	3	–	1	13
July	20	E 4546	0	0	0	6	20	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6	7	10		4	27
	21	E 5046	0	0	0	5	22	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	20	5		1	28
	22	E 5048	0	26	0	7	35	5	—	—	—	—	—	—	14	—	—	4	5	2	—	1	26	2	4	20	15		6	47
	26	E 6054	55	102	0	54	5	0	—	10	60	5	—	28	24	7	—	3	—	—	—	20	157	31	7	17	2		2	59
	27	E 6056	41	9	0	113	22	6	—	2	6	—	—	12	18	1	—	5	2	—	—	4	50	36	15	64	16		10	141
	28	E 6558	66	2	27	57	29	39	1	6	20	—	—	15	10	—	1	2	1	—	—	39	95	37	8	30	9		41	125
	29	E 7058	56	0	45	65	7	62	—	4	5	—	—	24	13	—	—	1	1	—	—	51	101	25	5	36	5		63	134
	30	E 7058	50	1	22	99	3	153	1	1	2	—	—	25	10	1	—	1	2	—	—	30	73	31	16	45	2		161	255
	31	E 7056	44	2	4	94	0	118	—	4	2	—	—	22	13	—	—	—	1	—	—	8	50	46	10	31	5		120	212
Aug.	1	E 7056	41	0	3	85	4	0	—	—	4	1	—	19	13	—	—	—	2	—	—	5	44	14	13	50	10		2	89
	3	E 6556	3	0	0	20	6	2	—	—	1	—	—	1	—	—	—	—	—	—	—	1	3	3	3	17	2		3	28
	4	E 6556	46	2	0	36	1	0	—	8	23	1	—	9	5	1	—	—	1	—	—	—	48	10	3	18	3		3	37
	5	E 7056	40	0	0	69	2	16	—	2	2	—	—	20	12	1	—	—	—	—	—	3	40	32	4	25	6		20	87
	6	E 7054	25	1	0	43	4	12	—	—	2	—	—	12	9	—	—	1	—	—	—	2	26	4	13	24	4		14	59
	8	E 7054	28	1	8	15	5	1	—	—	—	1	—	12	13	—	—	—	—	1	—	10	37	—	3	11	5		2	21
	9	E 6552	48	3	0	13	0	0	—	1	3	—	—	13	28	—	—	—	—	—	—	6	51	1	1	8	3			13
	10	E 6552	38	6	48	25	5	0	—	1	6	—	—	8	25	—	—	1	1	—	—	50	92	2	8	19	1			30
	11	E 6052	34	3	0	26	10	15	—	2	4	—	—	6	13	2	1	4	1	1	—	3	37	—	14	18	2		17	51
	14	E 6552	41	3	67	48	5	1	—	—	2	—	—	7	27	1	—	—	1	—	—	73	111	2	11	32	6		3	54
	15	E 6552	19	0	0	9	2	18	—	—	—	1	—	4	12	—	—	—	—	—	—	2	19	—	1	9	1		18	29
	16	E 6552	45	1	15	36	3	18	—	3	2	1	—	19	14	—	—	—	—	1	—	21	61	—	8	25	6		18	57
	17	E 7050	14	1	0	23	1	0	—	—	—	—	—	3	5	2	—	—	—	—	—	5	15	1	7	14	2			24
	18	E 6550	12	1	0	7	1	0	—	—	—	—	—	2	9	1	—	—	—	—	—	1	13	—	3	5	—			8

Date		Statistical area	Maturity: Sockeye I	Sockeye M	Sockeye ?	Chum I	Chum M	Chum ?	Age: Sockeye 3_2	4_3	5_4	3_1	4_2	5_3	6_4	4_1	5_2	6_3	7_4	Other	?	Total	Chum 2	3	4	5	6	?	Total
May	18	W7052	—	6			16	—	—	—	—	—	2	—	—	—	3	1	—	—	—	6	—	—	8	8	—	—	16
	19	W7052	—	1			38	6	—	—	—	—	—	1	—	—	—	—	—	—	—	1		—	23	15	—	6	44
	22	W7052	—	2	3	—	44	1	—	—	—	—	1	—	—	—	3	—	—	—	1	5	—	—	25	20	—	—	45
	23	W7550	2	223	10	3	59	1	—	—	—	—	142	21	4	—	32	20	—	—	16	235	—	1	26	35	—	1	63
	24	W7550	6	82	6	2	20	—	—	—	—	1	16	9	—	1	13	8	—	—	46	94	—	—	11	11	—	—	22
	27	W7546	1	1	2	69	13	4	—	—	—	—	1	—	—	—	1	—	—	—	2	4	—	—	79	5	—	2	86
	28	W7546	12	—	2	11	4	1	—	—	—	—	7	3	—	—	2	—	—	—	2	14	—	1	12	2	—	1	16
	29	W7544	51	1	8	4	—	—	1	2	—	—	37	14	—	—	3	—	—	—	3	60	—	—	3	1	—	—	4
	31	8046	4	—	—	45	25	3	—	—	—	—	2	—	—	—	2	—	—	—	—	4	-	3	60	8		2	73
June	1	8046	14	—	1	20	18	5	—	—	—	—	6	2	1	—	4	—	—	—	2	15	—	—	34	5	—	4	43
	4	8048	1	5	—	48	16	3	—	—	—	—	3	2	—	—	1	—	—	—	—	6		—	62	3		2	67
	5	E 7550	4	47		30	62	2		—	—	—	15	6	—	—	20	7	—	—	3	51	—	—	65	24	3	2	94
	6	E 7550	3	332	16	59	90	33	1	1	—	—	237	31	5	—	23	26	3	—	24	351	—	—	116	34	2	30	182
	7	8050	3	168	3	12	13	1	—	—	—	—	132	5	1	—	11	15	—	—	10	174	—	—	20	6	—	—	26
	15	8052	1	269	8	2	7	6	—	—	—	—	209	20	3	—	14	13	—	—	19	278	—	—	11	4	—	—	15
	16	8054	1	276	5	13	7	—	—	—	—	—	208	13	3	—	16	23	3	—	16	282	—	1	15	4	—	—	20
	17	8054	—	8	—	2	7	—	—	—	—	—	3	—	—	—	—	4	—	—	1	8	—	—	4	5	—	—	9
	18	W7556	2	62	3	7	11	—	—	—	—	—	39	6	—	—	6	9	2	—	5	67	—	—	13	5	—	—	18
	19	W7556	6	44	21	15	50	—	—	—	1	—	26	11	2	—	7	20	2	—	2	71	—	—	35	30	—	—	65
	20	W7556	—	274	6	41	28	2	—	—	—	—	169	26	7	—	22	37	2	—	17	280	—	—	58	12	—	1	71
	21	W7556	2	148	20	24	31	3	—	—	—	—	109	10	2	—	9	12	4	—	24	170	—	—	38	17	—	3	58
	22	W7054	—	251	8	7	5	1					211	12	2	—	8	9	1	—	16	259	—		12	—	—	1	13
	23	W7554	—	97	4	4	7	—	—	—	—	—	79	5	1	—	2	2	1	—	11	101	-	—	9	2	—	—	11
	24	W7054	—	190	6	105	86	7	—	1	—	—	152	19	1	—	2	3	—	—	18	196	—	8	176	7	1	6	198
	25	W7052	1	182	12	38	52	4	—	—	—	—	144	21	3	—	4	1	—	—	22	195	—	7	82	2	—	3	94
	26	W7052	8	59	31	123	35	7	—	—	—	—	44	16	9	—	7	13	—	—	9	98	—	8	148	4	—	5	165
	27	W7550	30	43	10	36	17	6	1	1	1	—	43	19	4	—	5	2	—	—	7	83	—	6	47	2	—	4	59
	28	W7550	58	12	30	61	25	3	—	1	—	—	51	25	3	—	3	6	—	—	11	100	—	12	74	3	—	—	89
	29	W7548	15	2	2	75	26	3	—	—	—	—	13	2	2	—	—	1	—	—	1	19	—	25	74	2	—	3	104
July	7	W7552	14	37	8	16	22	4	—	—	—	—	23	16	2	—	1	8	—	—	9	59	—	4	36	1	—	1	42
	8	W7552	6	16	4	12	3	5	—	—	—	—	10	5	—	—	1	2	—	—	8	26	—	8	10	—	—	2	20
	9	W7552	1	1	—	2			—	—	—	—	2	—	—	—	—	—	—	—	—	2	—	1	1	-			2
	11	W7550	91	49	43	12	5	—	1	2	—	—	80	26	8	—	20	16	3	—	27	183	-	8	7	2			17
	12	W7550	57	34	23	7	1	3	3	4	—	—	53	16	10	—	10	5	—	—	13	114	-	6	5	—	-		11
	13	W7550	53	15	4	36	10	5	1	1			29	21	9	—	2	1	—		8	72	1	26	22	1	—	1	51
	15*	W7550	27	4	2	55	1	1	—	2	—	—	14	9	2	—	—	3	—	—	3	33	3	42	11	—	—	1	57
	17	W7050	51	11	8	43	8	2	3	9	—	—	28	16	4	—	—	2	—	—	8	70	1	10	37	3	-	2	53
	18	W7550	170	38	22	105	10	4	7	27	—	—	99	43	3	—	6	14	—	—	31	230	1	73	44	1	—	—	119
	19	W7550	99	10	23	53	6	4	6	20	—	—	48	33	3	—	1	2	—	—	19	132	—	36	26	—	—	1	63
	20	W7550	67	50	21	53	6	13	3	12	—	—	41	28	5	—	7	14	1	—	27	138	1	53	11	—	—	7	72
	21	W7050	214	43	48	573	23	13	19	86	—	—	78	65	6	—	6	14	1	—	30	305	—	479	119	—	—	11	609
	23	W7052	35	38	14	468	12	61	1	21	—	—	7	28	3	—	3	8	1		15	87	2	395	92	1	—	51	541
	25	W7052	9	29	4	571	23	621	—	3	—	—	—	19	—	—	2	14	—	-	4	42	5	531	94	—	—	585	1215

* Day set.

Date		Statistical area	Maturity: Sockeye I	Sockeye M	Sockeye ?	Chum I	Chum M	Chum ?	Age: Sockeye 3_2	4_3	5_4	3_1	4_2	5_3	6_4	4_1	5_2	6_3	7_4	Other	?	Total	Chum 2	3	4	5	6	?	Total
May	28	E 7050	2	50	9	3	16	2	—	—	—	—	6	9	1	2	9	22	1	1	10	61	—	1	14	4	—	2	21
	29	E 7050	—	9	2	2	12	—	—	—	—	—	4	2	—	—	4	1	—	—	—	11	—	—	7	7	—	—	14
	30	E 7052	—	36	—	28	59	9	—	—	—	—	7	3	—	—	6	15	1	—	4	36	—	—	48	41	—	7	96
	31	E 7052	4	27	—	7	9	5	—	1	—	—	5	2	—	—	6	15	—	1	1	31	—	—	5	11	—	5	21
June	5	E 7054	—	8	1	1	43	3	—	—	—	—	—	2	—	—	1	5	—	—	1	9	—	—	21	23	—	3	47
	6	E 7052	1	10	—	1	13	—	—	—	—	—	1	—	—	—	5	5	—	—	—	11	—	—	6	8	—	—	14
	7	E 7052	—	7	1	—	3	1	—	—	—	—	3	1	—	—	—	3	—	—	1	8	—	—	1	2	—	1	4
	8	E 7052	4	34	2	43	26	1	—	—	—	—	11	5	—	—	8	13	—	—	3	40	—	1	47	20	—	2	70
	9	E 7552	—	5	1	8	9	1	—	—	—	—	3	—	—	—	—	1	—	—	2	6	—	1	9	7	—	1	18
	10	8052	—	7	1	2	5	2	—	—	—	—	3	2	—	—	1	—	—	—	2	8	—	—	5	2	—	2	9
	11	8052	—	28	—	9	8	1	—	—	—	—	22	2	—	—	—	4	—	—	—	28	—	—	13	4	—	1	18
	18	8052	2	109	13	4	1	7	—	—	—	—	93	8	—	—	2	3	—	—	18	124	—	—	7	3	—	2	12
	19	8054	4	192	8	16	8	6	1	3	—	1	150	14	—	—	9	11	—	—	15	204	—	—	22	2	—	6	30
	20	8054	—	124	11	26	5	6	—	—	—	—	92	18	2	—	4	14	—	—	5	135	—	2	28	3	—	4	37
	21	8054	—	20	4	61	18	10	—	1	—	—	13	2	—	—	2	3	—	—	3	24	—	2	63	14	—	10	89
	23	E 7554	—	42	1	1	4	—	—	—	—	—	16	10	1	—	1	12	1	—	2	43	—	—	5	—	—	—	5
	25	E 7054	1	7	2	22	6	2	—	1	—	—	2	2	—	—	—	4	—	—	1	10	—	—	23	6	—	1	30
	27	E 7552	2	6	6	206	5	15	—	—	—	—	6	2	—	—	1	3	—	—	2	14	—	7	196	8	—	15	226
	29	E 7050	59	15	17	49	4	5	—	6	—	—	43	17	1	—	5	9	—	—	10	91	—	9	44	—	—	5	58
	30	E 7550	69	12	27	11	1	3	15	12	—	—	37	25	—	—	3	3	—	—	13	108	—	2	9	1	—	3	15
July	2	8048	15	—	7	19	1	2	4	2	—	—	12	1	—	—	—	—	—	—	3	22	6	6	8	—	—	2	22
	3	8050	40	3	11	12	17	2	4	3	—	—	25	11	—	—	3	—	—	—	8	54	1	8	18	2	—	2	31
	4	8050	57	21	17	52	1	11	1	1	—	—	46	16	1	—	6	8	1	—	15	95	—	21	33	—	—	10	64
	14	E 7052	23	1	6	42	8	—	3	—	—	—	9	8	—	—	2	2	—	—	6	30	21	13	13	3	—	—	50
	16	E 7052	183	8	26	68	20	3	12	6	—	—	109	48	1	—	8	7	—	—	26	217	19	25	42	4	—	1	91
	17	E 7052	76	4	15	29	43	4	3	2	1	—	55	14	1	—	3	3	—	—	13	95	20	7	35	10	—	4	76
	18	E 7050	105	7	26	86	15	11	14	5	—	—	70	29	—	—	3	1	1	—	15	138	76	6	16	5	—	9	112
	19	E 7050	43	3	25	10	3	1	—	2	—	—	39	12	2	—	2	—	—	—	14	71	8	—	4	1	—	1	14
	27	E 7550	108	15	29	56	4	14	—	—	—	1	91	25	4	—	5	5	—	—	21	152	9	51	10	—	—	4	74
	28	E 7550	293	7	38	22	4	1	7	24	—	2	214	54	3	—	1	2	—	—	31	338	—	19	7	—	—	1	27
	29	E 7550	198	10	35	25	4	4	2	2	—	2	138	47	3	—	6	5	—	—	38	243	—	21	8	—	—	4	33
Aug.	1	E 7550	168	3	54	24	5	2	2	18	—	—	105	38	3	1	2	2	—	—	54	225	1	25	4	—	—	1	31
	14	8050	277	34	105	74	5	6	10	40	—	—	159	78	3	—	8	8	—	—	110	416	2	66	11	—	—	6	85
	17	8050	234	7	21	91	2	5	10	14	—	—	172	37	2	—	1	1	—	—	25	262	2	81	10	—	—	5	98
	18	8050	227	5	30	82	1	10	9	7	—	1	149	58	1	—	3	2	—	—	22	252	2	73	8	—	—	10	93
	20	8050	182	2	51	31	—	5	1	2	—	—	129	39	—	—	2	2	—	—	60	235	1	26	4	—	—	5	36
	24	W6052	1	1	—	36	2	1	—	—	—	—	2	—	—	—	—	—	—	—	—	2	—	37	1	—	—	1	39
	25	W6052	2	2	2	25	—	2	—	—	—	—	1	3	—	—	—	—	—	—	2	6	—	24	1	—	—	2	27
	26	W6054	1	1	2	2	3	1	—	—	—	—	—	1	—	—	1	—	—	—	2	4	1	1	3	—	—	1	6

APPENDIX TABLE C. WEIGHTED CATCH PER UNIT OF EFFORT OF SALMON BY SPECIES AND MATURITY AND AGE COMPOSITION OF SOCKEYE AND CHUM SALMON, 1955–1960

(Data are weighted to 3,000 feet of gillnet, each mesh size equally represented. CPUE values less than 0.5 are shown by a " plus " sign. In the table, " *I* " represents immature, " *M* " represents maturing and " ? " represents degree of maturation or age unknown. Both age and maturity data are lacking for sockeye and chum salmon in the Japanese data for 1955, 1956 and 1958 and in some United States data for 1955 and 1956 (*John N. Cobb*). Maturity data are lacking in the United States data for both species in 1955 (*Mitkof* and *Paragon*), for sockeye salmon in 1956 (all vessels) and for chum salmon in 1960 (all vessels).)

		Page
C- 1.	1955, *Tsukiyama-maru*	225
C- 2.	1955, *John N. Cobb*	226
C- 3.	1955, *Mitkof*	227
C- 4.	1955, *Paragon*	228
C- 5.	1956, *Challenger*	229
C- 6.	1956, *Key West II*	230
C- 7.	1956, *Eiko-maru*	230
C- 8.	1956, *Etsuzan-maru*	231
C- 9.	1956, *Takuyo-maru*	231
C-10.	1956, *Celtic*	232
C-11.	1956, *John N. Cobb*	233
C-12.	1956, *Mitkof*	233
C-13.	1956, *Paragon*	234
C-14.	1956, *Tordenskjold*	235
C-15.	1957, *Fort Ross*	236
C-16.	1957, *Key West II*	237
C-17.	1957, *Etsuzan-maru*	238
C-18.	1957, *Kano-maru*	239
C-19.	1957, *Attu*	240
C-20.	1957, *Paragon*	241
C-21.	1957, *Pioneer*	242
C-22.	1958, *Fort Ross*	243
C-23.	1958, *Key West II*	243
C-24.	1958, *Kano-maru*	244
C-25.	1958, *Wakashio-maru*	244
C-26.	1958, *Attu*	245
C-27.	1958, *Pioneer*	246
C-28.	1959, *Fort Ross*	247
C-29.	1959, *Key West II*	247
C-30.	1959, *Kano-maru*	248
C-31.	1959, *Pioneer*	249
C-32.	1959, *Tordenskjold*	250
C-33.	1960, *Etsuzan-maru*	251
C-34.	1960, *Paragon*	252
C-35.	1960, *Pioneer*	253

C-1. 1955, Tsukiyama-maru (Japan)

Date	Statistical area	Catch/3000 ft					Date	Statistical area	Catch/3000 ft				
		Sockeye	Chum	Pink	Coho	Chinook			Sockeye	Chum	Pink	Coho	Chinook
May 21	E 7044	29	24	32	—	—	July 2	E 7552	4	8	15	—	
22	E 7046	8	22	16	—	—	14	E 6554	34	23	5		
25	E 7548	13	40	2	—	—	15	E 6552	8	14	11	—	—
26	E 7548	17	55	+	—	—	16	E 6556	10	19	28	—	—
28	8052	1	1	—	—	—	17	E 7056	7	4	7	—	
June 2	8050	6	17	4	—	—	18	E 7056	4	12	7	—	+
3	8048	12	27	72	—	+	19	E 7556	4	64	5		
4	8048	4	10	22	—	+	20	E 7556	2	89	2		+
5	W7546	6	11	6	—	—	21	8056	+	19	+		
6	W7548	5	23	68	—	—	23	W7556	1	1	-		-
7	W7550	7	26	36	—	—	24	W7556	—	2		—	
8	W7550	10	8	28	—	—	25	W7558	—	+	-		—
9	W7550	24	26	22	—	+	26	W7558	—	1	—		+
10	W7550	5	9	39	—	—	27	W7558	—	8	—		
11	W7048	1	16	34	—	—	29	W7560	+	1	+	+	+
12	W7048	3	73	20	+	—	30	8058	—	3	—		—
13	W7048	3	6	9	—	—	31	8060	28	213	-		-
14	W7050	3	24	8	—	—	Aug. 1	E 7560	17	62		-	1
15	W7052	18	11	1	—	—	2	E 7560	16	113	-	+	5
17	W7054	70	24	2	—	+	4	E 7060	28	90	-	-	1
18	W7054	24	15	3	—	1	5	E 7058	26	30	-	—	—
19	W7554	5	+	—	—	—	6	E 6558	26	16	1	1	-
22	W7556	27	13	1	—	—	7	E 6558	38	39	1	3	1
23	W7556	1	+	+	—	—	8	E 6558	26	27	-	2	
24	W7058	2	1	+	—	—	9	E 6556	23	14	1	2	-
25	W7058	+	2	+	—	—	10	E 6056	19	8	+	1	
27	W7054	42	1	+	—	—	12	E 6052	8	12	-	20	
29	W7554	1	2	+	—	—	13	E 6052	13	13	1	8	-
30	8054	8	44	23	—	—	14	E 6052	13	45	1	5	
July 1	8054	5	20	23	—	—	16	E 6052	16	10	1	1	-

C-2. 1955, John N. Cobb (U.S.)

Date	Statistical area	Catch/3000 ft				
		Sockeye	Chum	Pink	Coho	Chinook
June 26	W3548	2	1	1	—	—
27	W3550	5	1	1	1	—
July 1	W4052	—	1	1	—	—
2	W3552	2	2	—	2	—
3	W4054	6	11	3	11	—
4	W4054	9	5	6	17	—
7	W4056	2	2	4	55	—
8	W4056	10	6	4	5	—
12	W4056	13	22	15	7	—
13	W4556	5	15	17	5	—
14	W4556	11	20	28	1	—
15	W5056	3	2	1	2	—
16	W5056	2	9	—	—	—
17	W5056	11	29	17	2	1
18	W5556	7	26	7	2	+
22	W5554	6	4	6	3	—
23	W5554	3	8	3	1	+
24	W5552	6	4	5	1	1
25	W5552	5	3	2	—	1
26	W6052	12	9	4	1	—
27	W6052	5	1	—	—	—
30	W6552	18	4	1	1	—
31	W6552	5	2	1	2	—
Aug. 1	W7052	14	10	—	—	—
2	W7052	50	5	4	+	1
Aug. 5	W6552	20	41	—	1	+
6	W6054	17	1	2	—	—
10	W5556	1	22	9	5	1
11	W5056	6	22	1	1	—
12	W5056	2	—	—	—	—
17	W4556	3	10	+	+	—
18	W4556	3	5	2	—	—
19	W4556	—	11	4	+	—
20	W4056	1	24	7	+	+
20*	W4056	+	2	3	—	—
21	W4056	—	3	6	+	—
22	W4056	+	6	33	—	—
22*	W4056	—	1	1	—	—
23	W4056	—	2	16	+	—
27	W4054	—	2	2	+	—
29	W4054	—	12	+	—	—
30	W4054	—	20	—	—	—
Sept. 6	W4056	—	3	1	—	—
7	W4056	—	55	—	+	—
8	W4556	—	44	—	—	2
9	W4556	—	18	—	1	—
10	W5056	—	10	—	—	—
10*	W5056	1	2	—	—	—
12	W4556	2	5	—	—	—
13	W4554	—	18	—	—	—

* Day set.

C-3. 1955, Mitkof (U.S.)

Date	Statistical area	Catch/3000 ft					Sockeye (ocean age)					Chum					
		Sockeye	Chum	Pink	Coho	Chinook	1	2	3	4	?	2	3	4	5	6	?
Aug. 12	W6552	23	23	—	—	—	9	12	1	—	1	3	15	3	—	—	2
13	W6550	38	18	—	—	—	4	31	—	—	3	5	8	5	—	—	—
14	W7050	2	18	—	—	—	—	1	—	—	1	5	5	7	—	—	1
15	W7048	1	2	—	—	—	—	1	—	—	—	1	1	—	—	—	—
16	W6548	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
17	W6546	—	—		—	—	—	—	—	—	—	—		—	—	—	—
18	W6546	—	—		—	—	—	—	—	—	—	—		—	—	—	—
19	W7044	—	—	—	—		—	—	—	—	—	—	—		—	—	—
20	W7044	—	—	—	—	—	—	—	—	—	—	—	—		—	—	—
21	W7544		—	—		—	—		—	—	—	—	—	—		—	
22	W7044	—	—	—	—	—	—	—	—	—	—	—		—	—	—	—
23	W7046	—	—	—	—			—		—		—		—			
24	W7546	—	—	—		—	—	—	—		—	—	—	—	—	—	
25	W7548		—		—	—	—	—	—	—	—		—	—	—	—	—
26	W7550	5	3	—	—	—	1	3	—	—	1	—	1	2	—	—	—
Sept. 3	W7550	18	6	—	—	+	4	12	1	—	1	—	2	3	—	—	1
4	8048	5	1	—	—	—	1	4	—	—	—	—	1	—	—	—	—
7	W7548	3	7	—	—	—	—	2	—	—	1	—	2	3	—	—	2
22	W5550	9	3	—	—	1	7	2	—	—	—	—	—	3	—	—	—
23	W5550	10	2	—	1	—	5	5	—	—	—	—	1	1	—	—	—
24	W5548	—		—			—		—	—	—	—	—	—	—	—	
25	W5546		—	—		—		—	—	—	—			—		—	
28	W4546		—		—	—	—	—	—	—	—	—		—		—	
Oct. 1	W3546		—		—	—	—	—	—	—	—						
3	W3046	—		—	—		—		—	—				—	—		
5	W3048		1	—	6	+	—	—	—	—	—	—	—	1	—	—	—

C-4. 1955. Paragon U.S.

Date	Statistical area	Catch/3000 ft					Sockeye (ocean age)					Chum					
		Sockeye	Chum	Pink	Coho	Chinook	1	2	3	4	?	2	3	4	5	6	?
Aug. 13	W7550	31	14	—	1	6	11	18	—	—	2	4	3	7			
14	W7548	3	12	—	—	—	—	3	—	—	—		8	4			
15	W7548	1	6	—	—	—	—	1					3	3			
16	W7546	—	—	—	—	—	—	—	—	—	—						
17	W7546	—	—	—	—	—	—	—	—	—	—						
18	W7544	—	—	—	—	—	—	—	—								
19	8044	—	—	—	—	—	—	—									
20	8044	—	—	—	—	—	—										
21	E 7544	—	—	—													
22	E 7544	—	—	—	—	—	—	—	—	—	—						
23	E 7546	—	—	—	—	—	—	—	—	—	—						
24	E 7546	—	—	—	—	—	—	—	—	—	—						
25	E 7548	—	—	—	—	—	—	—	—	—	—						
26	E 7548	—	—	—	—	—	—	—	—	—	—						
27	E 7550	1	19	—	—	—	1	—	—	—	—		9	10			
28	E 7550	14	50	—	—	—	11	3					34	15			1
Sept. 3	8050	18	83	—	—	—	10	7	1	—	—	1	35	43	3	—	1
4	8048	6	65	—	—	—	3	3	—	—	—		28	35	2		
13	E 7550	4	11	—	—	—	3	1	—	—	—		1	10			
14	E 7048	—	21	—	—	—	—	—	—	—	—		7	13	1		
15	E 7046	—	3	—	—	—	—	—	—	—	—		1	1	1		
16	E 7546	—	5										1	3	1		
17	E 7546	—	1											1			
19	8048	—	14	—	—	—	—	—	—	—	—		4	10			
20	W7550	4	9	—	—	—	3	1	—	—	—		6	3			
Oct. 3	W4550	—	—	—	—	—	—	—	—	—	—						

C-5. 1956, Challenger (Canada)

Date		Statistical area	Catch/3000 ft					Maturity				Sockeye (ocean age)					Chum				
			Sockeye	Chum	Pink	Coho	Chinook	Sockeye		Chum		1	2	3	4	?	2	3	4	5	6
								I	*M*	*I*	*M*										
June	3	W3548	—	—	3	6		—	—	—	—	—	—	—	—	—	—	—	—		
	4	W3548	3	3	—	5	—	—	3	—	3	3	—	—	—	—	—	—	—	—	3
	7	W4548	7	1	3	3	2	5	2	—	1	3	4	—	—	—	—	—	1		
July	8	W4054	3	7	—	9	—	—	3	7	—	—	3	—	—	—	3	4	—	—	—
	9	W4056	5	21	2	8	1	—	5	9	12	1	3	1	—	—	9	8	4	—	—
	10	W4058	10	11	11	6	—	—	10	—	11	1	5	4	—	—	—	2	8	1	—
	11	W4058	7	5	4	5	—	—	7	3	2	2	3	2	—	—	1	3	1	—	—
	12	W4558	7	1	13	9	—	1	6	—	1	1	4	1	—	1	—	—	1	—	—
	13	W5058	1	6	—	1	—	—	1	1	5	—	—	1	—	—	—	3	3	—	—
	17	W5056	13	22	14	3	—	9	4	20	2	3	7	—	—	3	—	13	8	1	—
	18	W5054	6	10	11	3	1	4	2	9	1	2	3	1	—	—	—	8	2	—	—
	19	W5052	3	5	4	1	—	3	—	4	1	1	2	—	—	—	—	4	1	—	—
	20	W5050	11	6	1	—	—	10	1	6	—	4	6	1	—	—	4	2	—	—	—
	23	W4050	—		—	—		—	—			—	—	—	—	—	—	—			
	24	W4050	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
	25	W4050	—		—	—			—	—						—					
	26	W3550	—	—	—	—	—	—	—	—	—	—	—			—					
Aug.	12	W3050	—	—	—	—	—		—	—	—		—	—							
	15	W3552	—	1	2	—	—	—	—	—	1	—	—	—	—	—	—	—	1		
	16	W3554	—	—	1	—		—	—		—		—	—	—	—					
	22	W3554	—	13	16	5	—	—	—	3	10	—	—	—	—	—	1	7	5	—	—
	23	W4054	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
	25	W3550	—	—	—	—			—	—					—	—					
	26	W3048	—	—		—		—	—	—	—		—	—	—	—		—			
Sept.	6	W4054	—	—	1		—	—			—	—	—			—					
	7	W4054	—	3	—	—	—	—	—	1	2	—	—	—	—	—	—	2	1	—	—
	8	W4052	—	—	—		—	—	—		—	—	—		—						
	9	W4052	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	10	W3550	—	—	—	—	—	—	—	—	—	—	—	—	—	—					

C-6. 1956, Key West II (Canada)

Date	Statistical area	Catch/3000 ft					Maturity				Sockeye (ocean age)					Chum				
		Sockeye	Chum	Pink	Coho	Chinook	Sockeye		Chum		1	2	3	4	?	2	3	4	5	6
							I	*M*	*I*	*M*										
May 23	W3554	4	—	—	—	—	—	4	—	—	—	2	2	—	—	—	—	—	—	—
28	W3552	9	9	3	1	—	9	—	9	—	8	—	—	—	1	—	8	1	—	—
29	W3050	—	—	4	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
31	W3048	1	—	1	—	—	1	—	—	—	1	—	—	—	—	—	—	—	—	—
June 18	W3546	—	—	2	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
19	W3544	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
20	W3542	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
21	W3042	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
22	W3042	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
26	W3044	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
27	W3046	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
July 12	W4056	2	—	4	4	—	—	2	—	—	—	1	1	—	—	—	—	—	—	—
13	W4556	5	5	10	6	—	2	3	5	—	3	—	2	—	—	—	4	1	—	—
14	W4554	5	30	5	3	—	3	2	30	—	2	1	1	—	1	—	27	3	—	—
15	W4552	9	13	4	4	1	9	—	13	—	6	—	—	—	3	—	9	3	—	1
17	W4052	7	12	4	—	—	—	7	12	—	—	5	2	—	—	7	5	—	—	—
18	W4054	1	17	8	—	—	—	1	17	—	—	1	—	—	—	17	—	—	—	—
19	W4052	—	1	3	—	—	—	—	1	—	—	—	—	—	—	1	—	—	—	—
20	W3552	5	8	4	1	—	—	5	2	6	—	5	—	—	—	2	4	1	—	1

C-7. 1956, Eiko-maru (Japan)

Date	Statistical area	Catch/3000 ft					Date	Statistical area	Catch/3000 ft				
		Sockeye	Chum	Pink	Coho	Chinook			Sockeye	Chum	Pink	Coho	Chinook
May 24	E 7048	2	20	—	—	—	July 10	E 7050	26	26	—	—	—
26	E 7548	—	—	—	—	—	13	E 7046	—	1	—	2	—
27	E 7548	7	2	+	—	—	17	E 6546	—	2	13	7	+
28	8048	1	12	1	—	—	18	E 6546	—	4	25	22	—
30	E 7546	2	1	2	—	—	19	E 6546	—	4	12	8	—
31	E 7546	3	5	1	—	—	20	E 6546	—	11	9	6	2
June 1	E 7548	6	4	4	—	—	21	E 6546	—	5	5	3	—
2	E 7548	2	5	—	—	—	25	E 6552	44	7	+	3	1
3	E 7050	—	—	—	—	—	26	E 6554	14	8	+	—	—
5	E 7052	12	13	+	—	—	27	E 6556	5	17	—	+	—
6	E 7052	3	32	—	—	+	28	E 6556	11	61	+	+	—
7	E 7052	15	50	2	—	—	29	E 6556	42	38	+	+	—
8	E 7552	4	37	10	—	—	30	E 6056	28	43	+	+	—
9	E 7554	2	5	+	—	—	31	E 6054	23	20	+	+	—
10	E 7556	1	11	+	—	—	Aug. 1	E 6556	12	8	+	—	—
13	E 7556	5	13	+	—	—	2	E 6556	14	21	11	—	—
14	E 7554	6	26	3	—	—	3	E 6554	4	9	7	—	—
15	8052	11	5	1	—	—	4	E 6554	5	27	8	—	—
16	8052	7	7	+	—	—	5	E 6554	1	7	4	+	+
17	8052	21	3	+	—	+	6	E 6552	19	9	7	1	—
18	W7554	18	2	1	—	+	7	E 6552	23	10	5	4	+
19	8056	14	5	+	—	—	8	E 6552	11	7	3	2	—
20	8056	35	16	+	—	+	9	E 6552	5	6	5	2	—
July 6	8052	6	14	+	—	—	10	E 6552	9	11	6	8	—
7	E 7552	10	36	—	—	+	11	E 6552	10	5	3	5	—
8	E 7552	—	—	—	—	—							

C-8. 1956, ETSUZAN-MARU (Japan)

Date	Statistical area	Catch/3000 ft Sockeye	Chum	Pink	Coho	Chinook
May 19	W7538	—	—	—	—	—
25	W7042	—	—	3	—	—
28	8042	×	×	×	×	×
30	8042	—	+	×	—	—
June 1	8044	+	21	×	—	—
5	W7546	10	6	×	—	1
8	W7046	9	7	×	+	—
10	W7048	6	12	×	—	—
15	8048	6	12	×	—	—
17	E 7550	16	45	22	—	1
18	E 7050	5	8	+	—	—
19	E 7052	×	×	×	×	×
20	E 7050	×	×	×	×	×
22	E 7552	2	1	×	—	—
23	8052	23	37	×	—	—
30	8052	×	×	×	×	×
July 6	8054	13	13	+	—	—
7	E 7554	13	66	+	—	+
9	E 7054	14	49	+	+	+
15	E 7048	—	14	×	25	+
16	E 7048	—	8	4	25	+
July 17	E 6546	×	×	×	×	
18	E 6546	×	×	×	×	
19	E 6546	—	+	+	1	—
20	E 6546	—	9	2	3	—
21	E 6546	—	6	3	5	+
26	E 6556	41	69	—	—	—
27	E 6556	15	23	+	—	+
28	E 6556	34	92	—	—	—
29	E 6556	25	35	+	—	—
30	E 6558	61	46	—	+	—
31	E 6556	18	9	—	+	—
Aug. 1	E 6556	32	28	—	—	—
2	E 6556	26	27	—	+	—
3	E 6556	27	27	+	+	+
5	E 6554	21	42	+	1	+
6	E 6552	36	30	+	1	—
7	E 6552	56	26	+	1	+
8	E 6552	41	27	+	1	1
9	E 6552	29	16	—	1	+
10	E 7052	51	12	+	—	+

× Weighted value not available since catches by gillnets of varying mesh sizes were not recorded.

C-9. 1956, TAKUYO-MARU (Japan)

Date	Statistical area	Catch/3000 ft Sockeye	Chum	Pink	Coho	Chinook
May 14	E 6038	—	—	—	—	—
18	E 7038	—	—	—	—	—
20	E 7542	—	2	12	—	—
24	E 6542	—	3	8	—	—
27	E 6044	17	16	8	—	+
29	E 7044	28	2	16	1	—
31	E 7044	45	11	6	2	—
June 1	E 7546	20	7	12	—	1
6	E 7048	11	5	8	3	—
7	E 7050	3	25	5	—	+
15	E 7048	57	37	9	—	—
17	E 7548	28	24	3	1	—
18	E 7548	6	15	+	+	—
19	E 7548	7	2	+	+	+
20	8050	15	54	—	—	—
22	8052	10	+	+	—	—
23	8052	5	1	+	—	—
July 7	E 7554	4	81	2	—	—
14	E 6546	—	13	26	8	+
15	E 6546	—	13	19	4	—
16	E 6546	—	8	6	2	—
July 17	E 6546	—	4	5	2	—
18	E 6546	—	7	10	10	+
19	E 6546	—	7	20	27	1
21	E 6546	—	12	4	3	+
25	E 6552	9	7	1	1	
26	E 6552	44	28	+	1	
27	E 6552	66	13	+	1	
29	E 6052	48	12	2	2	
30	E 6052	31	77	1	6	2
31	E 6052	75	7	1	4	
Aug. 1	E 6552	37	9	+	1	+
2	E 6552	47	29	+	3	
3	E 6552	29	13	+	2	+
5	E 6552	32	5	+	4	
6	E 6552	49	5	1	3	
7	E 6552	34	6	+	3	
8	E 6552	25	6	+	3	-
10	E 6050	+	19	+	2	+
11	E 6050	7	9	2	4	+
12	E 6048	—	3	5	4	

C-10. 1956, Celtic (U.S.)

Date		Statistical area	Catch/3000 ft					Maturity				Sockeye (ocean age)				Chum					
			Sockeye	Chum	Pink	Coho	Chinook	Sockeye[1]		Chum		1	2	3	4	2	3	4	5	6	?
								I	*M*	*I*	*M*										
July	13	W4552	8	48	6	1	—	—	—	48	—	3	2	3	—	1	42	4	—	—	1
	14	W4552	6	23	1	—	+	—	—	23	—	1	5	—	—	1	21	1	—	—	—
	16	W4550	2	15	1	—	—	—	—	15	—	—	1	1	—	1	10	3	—	—	1
	17	W4550	2	68	1	6	+	—	—	68	—	1	—	1	—	49	13	1	—	—	5
	18	W4548	1	14	—	—	—	—	—	14	—	—	1	—	—	6	6	1	—	—	1
	19	W4548	—	3	—	—	—	—	—	3	—	—	—	—	—	2	1	—	—		
	21	W5048	1	20	—	2	—	—	—	20	—	—	1	—	—	9	6	1	—	—	4
	22	W5048	5	45	—	1	+	—	—	45	—	4	1	—	—	27	15	2	—		1
	23	W5050	4	51	—	1	—	—	—	51	—	3	1	—	—	33	14	1	1		2
	24	W5050	15	37	1	1	+	—	—	37	—	13	2	—	—	23	11	2	—		1
	25	W5052	5	15	1	2	—	—	—	14	1	3	2	—	—	1	11	1	—		2
	26	W5052	8	12	4	1	—	—	—	11	1	1	6	1	—	—	8	3	—	—	1
	31	W4558	2	36	22	2	—	—	—	33	3	—	1	1	—	31	2	2	—		1
Aug.	1	W4558	3	12	21	3	—	—	—	6	6	—	2	1	—	—	5	5	—		2
	2	W4556	2	37	20	1	—	—	—	37	—	—	1	1	—	35	2	—	—	—	
	3	W4556	—	25	7	2	—	—	—	24	1	—	—	—	—	4	15	5	—	—	1
	4	W4554	3	13	1	1	—	—	—	12	1	—	2	1	—	3	7	1	—	—	2
	5	W4554	5	12	—	—	1	—	—	11	1	—	5	—	—	1	8	1	—	—	2
	7	W5054	14	31	1	—	—	—	—	31	—	5	9	—	—	8	21	1	—	—	1
	8	W5054	5	14	3	—	—	—	—	14	—	—	4	1	—	3	9	—	—	—	2
	9	W5556	5	9	6	1	—	—	—	9	—	—	4	1	—	6	2	1	—	—	
	10	W5056	3	12	4	—	—	—	—	12	—	—	2	1	—	6	3	—	—	—	3
	11	W5058	4	5	31	6	1	—	—	3	2	—	3	1	—	2	1	1	—	—	1
	17	W5554	2	42	—	—	—	—	—	37	5	—	1	1	—	11	22	7	—	—	2
	18	W5554	27	22	—	1	—	—	—	19	3	6	20	1	—	15	5	1	—	—	1
	19	W5552	50	25	—	—	—	—	—	24	1	15	33	2	—	9	6	1	—	—	9
	20	W5552	20	2	—	—	—	—	—	2	—	3	17	—	—	—	1	1	—	—	
	21	W5552	14	5	—	—	+	—	—	4	1	1	13	—	—	—	4	1	—		—
	22	W5550	18	25	—	—	+	—	—	24	1	13	5	—	—	15	7	1	—		2
	23	W5550	10	21	—	—	—	—	—	21	—	8	2	—	—	17	3	1	—	—	—
	26	W5548	—	10	—	—	—	—	—	10	—	—	—	—	—	3	1	1	—	—	5
	28	W5548	—		—		—			—	—	—	—			—					
	30	W5048		—		—		—		—	—	—									
	31	W5048		—			—	—	—						—						
Sept.	1	W5050	—	3	—	—	—	—	—	3	—	—	—	—	—	1	1	1	—		
	2	W5050	2	21	—	—	—	—	—	21	—	2	—	—	—	19	1	—	—	—	1
	3	W5052	9	32	—	—	—	—	—	30	2	8	1	—	—	21	8	1	—	—	2
	4	W5052	20	21	—	—	—	—	—	20	1	5	15	—	—	3	13	2	—	—	3
	12	W4552	2	6	—	—	—	—	—	6	—	2	—	—	—	2	4	—	—		
	13	W4552	—		—		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	14	W4550			—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	15	W4550		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	17	W4052		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	18	W4050	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	19	W4050	—		—					—	—										

[1] Maturity data for sockeye salmon are lacking.

C-11. 1956, John N. Cobb (U.S.)

Date	Statistical area	Catch/3000 ft				
		Sockeye	Chum	Pink	Coho	Chinook
July 18	W3046	—	—	—	—	—
19	W3044	—	—	—	—	—
21	W3546	—	—	—	—	—
23	W3550	2	—	—	—	—
24	W4050	2	—	—	1	—
25	W4050	1	—	—	—	—
26	W4048	—	—	—	—	—
27	W4046	—	—	—	—	—
28	W4046	—	—	—	—	—
30	W3546	—	—	—	—	—
Aug. 1	W3046	—	—	—	—	—
2	W3044	—	—	—	—	—
7	W3046	—	—	—	—	—
9	W3040	—	—	—	—	—
Aug. 15	W3544					
17	W4044					
19	W4546					
20	W4546	—	—	—	—	—
21	W4548					
22	W4550					
23	W4548	—	—	—	1	—
24	W4048	—	—	—	—	—
25	W4048					
26	W4048					
27	W3548	—			—	
28	W3550	—			—	
29	W3050	—				

C-12. 1956, Mitkof (U.S.)

Date	Statistical area	Catch/3000 ft					Maturity				Sockeye (ocean age)				Chum					
		Sockeye	Chum	Pink	Coho	Chinook	Sockeye[1]		Chum		1	2	3	4	2	3	4	5	6	?
							I	*M*	*I*	*M*										
May 17	W3048	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—		
22	W4548	5	5	—	1	1	—	—	—	5	1	4	—	—	—	1	2	—	—	2
25	W5046	6	3	—	—	1	—	—	—	3	4	1	1	—	—	—	1	2	—	—
28	W6050	2	—	—	—	—	—	—	—	—	—	2			—		—			
June 15	E 7550	6	22	1	—	—	—	—	11	11	1	4	1	—	—	3	10	9	1	—
16	E 7550	45	30	2	—	—	—	—	26	4	15	23	7	—	—	21	5	3	—	1
19	E 7542		—	—					—	—	—		—	—						
22	W7542	—		—	—	—	—	—	—		—	—	—	—		—				
26	8050	8	3	—	—	1	—	—	1	2	1	6	1	—	2	—	1			
July 6	8052	4	9	—	—	—	—	—	9	—	—	3	1	—	3	5	1	—	—	—
7	8054	16	39	1	—	—	—	—	37	2	3	5	8	—	16	15	6	1	—	1
8	8054	8	150	1	—	1	—	—	150	—	1	4	3	—	86	58	2	3	—	1
9	8056	5	106	—	—	6	—	—	106	—	3	1	1	—	85	14	3	1	—	3
10	8056	4	24	—	—	3	—	—	24	—	1	2	1	—	14	8	1	1	—	—
11	8058	8	66	—	—	—	—	—	64	2	3	4	1	—	11	41	8	4	—	2
13	W7560	2	4	—	—	—	—	—	2	2	—	1	1	—	—	—	—	4	—	—
14	W7558	—	3	—	—	—	—	—	—	3	—	—	—	—	—	—	—	2	—	1
15	W7558	7	57	—	—	2	—	—	55	2	2	3	2	—	25	20	3	4	—	5
17	W7556	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Aug. 3	W7554	4	2	—	—	—	—	—	1	1	—	4	—	—	—	—	1	1	—	—
4	W7552	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
5	W7552	1	18	—	—	—	—	—	17	1	—	1	—	—	2	11	4	1	—	—
8	W7550	33	14	—	—	1	—	—	12	2	7	25	1	—	1	7	3	3	—	—
9	W7548	3	30	—	—	1	—	—	27	3	1	2	—	—	3	18	6	1	—	2
10	W7548	1	5	—	—	—	—	—	5	—	1	—	—	—	—	2	2	—	—	1
11	W7548	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
12	W7546	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
14	8046	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
15	8048	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
16	8048	—	2	—	—	—	—	—	2	—	—	—	—	—	—	—	1	—	—	1
17	8050	—	21	—	—	—	—	—	21	—	—	—	—	—	1	18	1	1	—	—
23	8050	96	13	1	1	3	—	—	12	1	59	36	1	—	3	4	3	1	—	2
25	E 7550	118	37	—	—	—	—	—	36	1	31	85	2	—	—	12	10	8	1	7
26	E 7550	7	12	—	—	2	—	—	11	1	—	6	1	—	—	6	3	2	—	1
27	E 7548	—	9	—	—	+	—	—	9	—	—	—	—	—	—	5	3	—	—	1
28	E 7548	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
Sept. 2	8046	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	8048	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
4	8048	—	3	—	—	—	—	—	2	1	—	—	—	—	—	1	1	1	—	
5	8050	—	13	—	—	—	—	—	10	3	—	—	—	—	—	3	5	4	—	1
16	W6054	1	4	—	—	—	—	—	1	3	—	1					1	1	1	3

[1] Maturity data for sockeye salmon are lacking.

C-13. 1956. Paragon (U.S.)

Date		Statistical area	Catch/3000 ft					Maturity				Sockeye (ocean age)				Chum				
			Sockeye	Chum	Pink	Coho	Chinook	Sockeye[1]		Chum		1	2	3	4	2	3	4	5	6
								I	*M*	*I*	*M*									
July	12	W4058	5	9	23	3	—	—	—	5	4	—	3	2	—	—	2	7	—	—
	13	W4558	7	72	11	1	—	—	—	51	21	—	2	5	—	—	40	31	1	—
	15	W5058	1	—	1	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—
	20	W5554	25	39	15	3	—	—	—	35	4	6	14	5	—	—	24	14	—	—
	21	W5554	21	21	4	2	—	—	—	16	5	3	13	5	—	—	6	15	—	—
	22	W5552	7	3	—	1	+	—	—	2	1	—	6	1	—	—	—	3	—	—
	23	W5552	13	8	2	1	—	—	—	6	2	4	7	2	—	—	6	1	—	—
	24	W5550	19	6	1	2	—	—	—	4	2	10	9	—	—	1	3	2	—	—
	25	W5550	2	14	+	4	1	—	—	14	—	1	1	—	—	5	7	2	—	—
	26	W5548	1	18	—	1	—	—	—	18	—	1	—	—	—	11	5	2	—	—
	27	W5548	1	1	—	—	—	—	—	1	—	1	—	—	—	1	—	—	—	—
	28	W5546	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	29	W5544	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	31	W6544	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Aug.	1	W6046	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	2	W6048	—	3	—	—	—	—	—	2	1	—	—	—	—	—	1	2	—	—
	3	W6048	1	12	—	—	1	—	—	10	2	1	—	—	—	—	7	4	1	—
	4	W6050	6	17	—	—	—	—	—	17	—	1	5	—	—	1	9	7	—	—
	5	W6550	5	22	—	1	—	—	—	22	—	3	2	—	—	4	15	3	—	—
	6	W6050	7	14	—	—	—	—	—	14	—	1	6	—	—	—	8	5	—	—
	7	W6052	13	7	—	—	1	—	—	6	1	—	13	—	—	—	4	2	1	—
	8	W6054	8	36	1	—	—	—	—	10	26	1	5	2	—	—	25	11	—	—
	19	W7052	18	2	—	—	—	—	—	2	—	17	1	—	—	—	2	—	—	—
	20	W7050	19	12	—	—	—	—	—	12	—	10	8	1	—	—	7	5	—	—
	21	W7050	12	24	—	—	1	—	—	23	1	10	2	—	—	1	10	11	1	—
	22	W7048	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	25	W7046	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	27	W6546	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	28	W6546	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	29	W6548	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	30	W6548	—	4	—	—	—	—	—	4	—	—	—	—	—	—	3	1	—	—
	31	W6550	3	22	—	—	—	—	—	20	2	1	1	1	—	2	14	6	—	—
Sept.	2	W6552	14	15	—	—	—	—	—	15	—	6	8	—	—	5	9	1	—	—
	3	W6552	6	10	1	1	1	—	—	9	1	1	3	2	—	3	4	3	—	—
	7	W6552	1	1	—	—	—	—	—	1	—	—	—	1	—	—	1	—	—	—
	8	W6552	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	10	W6550	3	7	—	—	—	—	—	7	—	1	2	—	—	1	4	2	—	—
	11	W6550	1	5	—	—	—	—	—	5	—	—	1	—	—	—	4	1	—	—
	12	W6548	—	10	—	—	—	—	—	10	—	—	—	—	—	—	2	8	—	—
	14	W6048	—	2	—	—	—	—	—	2	—	—	—	—	—	—	1	1	—	—
	15	W5548	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	17	W5048	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	22	W3548	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	24	W3050	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

[1] Maturity data for sockeye salmon are lacking.

C-14. 1956, Tordenskjold (U.S.)

Date		Statistical area	Catch/3000 ft					Maturity				Sockeye (ocean age)[1]				Chum					
			Sockeye	Chum	Pink	Coho	Chinook	Sockeye[1]		Chum		1	2	3	4	2	3	4	5	6	?
								I	*M*	*I*	*M*										
May	25	W5058	1	1	—	—	—	—	—	—	1	—	—	—	—	—	—	—	1		
	31	W6552	17	14	—	—	1	—	—	—	14	—	—	—	—	6	7	1	—	—	—
June	7	W6554	26	7	—	—	—	—	—	—	7	—	—	—	—	—	—	2	4	—	1
	8	W6556	1	6	—	—	+	—	—	—	6	—	—	—	—	—	—	2	4	—	—
	9	W6556	1	6	—	—	—	—	—	—	6	—	—	—	—	—	—	5	1	—	—
	10	W6056	—	1	—	—	—	—	—	—	1	—	—	—	—	—	—	1	—	—	
	11	W6056	1	1	—	—	+	—	—	—	1	—	—	—	—	—	—	—	1	—	
	13	W6558	1	19	2	—	—	—	—	—	19	—	—	—	—	—	—	15	4	—	—
	14	W6558	1	53	1	—	+	—	—	—	53	—	—	—	—	—	—	35	18	—	—
	16	W7060	1	8	1	—	—	—	—	—	8	—	—	—	—	—	—	5	3	—	—
	17	W7058	1	24	3	—	—	—	—	—	24	—	—	—	—	—	—	14	10	—	—
	18	W7058	1	13	2	—	+	—	—	—	13	—	—	—	—	—	—	8	5	—	—
	20	W7056	404	26	2	—	2	—	—	—	26	—	109	24	1	—	—	12	3	—	11
	21	W7054	301	28	4	—	+	—	—	4	24	—	—	—	—	—	—	18	9	—	1
	25	W7054	36	8	—	—	—	—	—	1	7	—	—	—	—	—	—	2	1	—	5
July	29	W7054	1	1	1	1	—	—	—	—	1	—	—	—	—	—	—	1			
	30	W7554	1	—	—	—	—	—	—	—	—										
	31	W7554	1	4	—	—	—	—	—	—	—	—	—	—	—	—	—	2	1	—	1
Aug.	2	W7058	2	2	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—
	3	W7058	—	13	—	1	—	—	—	13	—	—	—	—	—	—	1	6	6	—	—
	4	W7558	—	3	—	1	+	—	—	—	—	—	—	—	—	—	—	2	1	—	—
	5	W7058	1	5	1	—	—	—	—	—	—	—	—	1	—	—	1	5	—	—	—
	6	W7058	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	2			
	7	W7056	1	5	—	—	—	—	—	—	—	—	1	—	—	—	—	4	1	—	—
	8	W6558	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
	9	W6058	1	1	—	3	5	—	—	—	—	—	—	1	—	—	—	1	—		
	11	W6556	2	—	—	1	1	—	—	—	—	1	1	—	—	—	—	—	—	—	
	12	W6556	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—		
	13	W6556	1	1	—	1	2	—	—	—	—	—	1	—	—	—	—	1	—		
	14	W6556	5	3	—	1	—	—	—	—	—	—	—	—	—	—	1	2	—	—	—
Sept.	12	W7054	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	14	W7054	1	5	—	—	—	—	—	—	—	—	1	—	—	—	1	2	1	—	1
	15	W7554	—	—	—	—	+	—	—	—	—	—	—	—	—	—	—	—	—		
	16	W7056	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	17	W7058	1	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—
	19	W6556	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
	21	W7054			—					—	—										

[1] Maturity data are lacking and data on ocean age are incomplete for sockeye salmon.

C-15. 1957, Fort Ross (Canada)

Date	Statistical area	Catch/3000 ft					Maturity				Sockeye (ocean age)					Chum				
		Sockeye	Chum	Pink	Coho	Chinook	Sockeye		Chum		1	2	3	4	?	2	3	4	5	?
							I	*M*	*I*	*M*										
May 19	W3554	1	2	—	—	—	—	1	—	2	—	—	1	—	—	—	—	2	—	—
20*	W3552	—	1	—	1	—	—	—	—	1	—	—	—	—	—	—	—	1	—	—
21	W3552	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
22*	W3552	1	1	—	—	—	—	1	—	1	—	—	1	—	—	—	—	1	—	—
23	W3552	1	19	—	1	—	—	1	1	5	—	1	—	—	—	—	4	14	1	—
June 8	W3550	7	16	7	27	—	1	6	14	2	—	6	—	—	1	8	6	—	—	2
9*	W3550	13	12	5	12	—	1	12	10	2	1	10	2	—	—	6	4	—	—	2
10	W3550	12	12	2	5	—	—	12	10	2	—	8	1	—	3	7	3	—	—	2
14	W4550	14	4	5	8	—	10	4	3	1	12	2	—	—	—	1	3	—	—	—
21	W5550	4	2	1	—	—	3	1	2	—	2	1	—	—	1	—	1	1	—	—
22*	W5550	2	2	1	1	1	2	—	2	—	1	—	—	—	1	—	1	1	—	—
23	W5550	32	3	4	2	1	32	—	3	—	26	5	—	—	1	1	2	—	—	—
24	W5550	1	—	—	1	—	1	—	—	—	—	1	—	—	—	—	—	—	—	—
28	W4550	3	6	6	1	—	3	—	6	—	2	1	—	—	—	5	1	—	—	—
30	W4550	2	18	5	8	—	—	2	18	—	1	1	—	—	—	15	2	—	—	1
July 2	W4050	17	1	—	—	—	1	16	1	—	4	13	—	—	—	1	—	—	—	—
3	W3550	7	3	2	—	—	—	7	3	—	—	4	3	—	—	1	2	—	—	—
20	W3550	35	—	1	—	—	—	35	—	—	5	29	1	—	—	—	—	—	—	—
21	W3550	3	—	—	—	—	—	3	—	—	1	2	—	—	—	—	—	—	—	—
24	W4550	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
26	W4550	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
28	W5550	1	3	—	—	—	1	—	3	—	1	—	—	—	—	1	2	—	—	—
29	W5550	1	2	—	—	—	1	—	2	—	1	—	—	—	—	1	1	—	—	—
30	W5552	10	1	—	—	—	9	1	1	—	9	1	—	—	—	1	—	—	—	—
31	W5552	4	6	—	—	—	4	—	6	—	3	1	—	—	—	4	2	—	—	—
Aug. 2	W4552	—	5	—	—	—	—	—	5	—	—	—	—	—	—	4	1	—	—	—
4	W4552	2	6	1	1	—	—	2	6	—	1	1	—	—	—	5	1	—	—	—
6	W3552	—	2	—	1	—	—	—	2	—	—	—	—	—	—	—	2	—	—	—
7	W3552	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
8	W3552	—	2	—	—	—	—	—	—	2	—	—	—	—	—	—	1	1	—	—
18	W3552	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
19	W3552	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
22	W4050	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
25	W3548	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
26	W3548	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
27	W3548	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
28	W3048	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

* Day set.

C-16. 1957, Key West II (Canada)

Date		Statistical area	Catch/3000 ft					Maturity				Sockeye (ocean age)					Chum				
			Sockeye	Chum	Pink	Coho	Chinook	Sockeye		Chum		1	2	3	4	?	2	3	4	5	?
								I	*M*	*I*	*M*										
May	13	W3046	—	—	—	1	1	—							—						
	14*	W3046	—		—	—	—	—	—	—	—	—	—	—	—		—			—	
	15	W3046	—	1	1	—	—	—	—	1	—	—	—	—	—	—	1	—	—	—	—
	16	W3544					—	—	—	—	—	—			—	—	—	—	—	—	
	17	W3542					—	—	—	—				—	—	—			—	—	—
	18	W3544	—	—	—	—	—	—	—	—	—	—	—	—	—	—		—			
	26	W3544	—	—	—	1	—	—	—	—	—	—	—	—	—		—	—			
	27	W4044	—	—	—	—	—	—	—	—	—	—	—	—	—		—			—	—
	28	W4046	—	1	3	—	—	—	—	1	—	—	—	—	—	—	1	—	—	—	—
	29	W3548	—	1	—	—	—	—	—	1	—	—	—	—	—	—	—	1	—	—	—
	30	W3548						—	—	—	—	—	—	—	—	—			—	—	
June	14	W3554	3	37	2	4	—	—	3	1	25	—	2	1	—	—	—	7	23	2	5
	15	W3554	7	63	4	5	—	—	7	4	32	—	3	4	—	—	—	21	36	1	5
	29	W4554	2	19	1	3	1	1	1	19	—	—	2	—	—	—	—	17	1	—	1
July	1	W5554	6	4	2	1	—	3	3	3	1	—	4	2	—	—	—	1	2	1	—
	3	W5554	27	11	2	—	—	10	6	10	1	5	18	3	—	1	—	7	3	1	—
	8	W4558	13	5	2	—	—	1	12	4	1	—	7	6	—	—	—	4	1	—	—
	9	W4558	3	14	3	3	—	—	3	13	1	—	2	1	—	—	1	12	1	—	—
	10	W4558	5	3	5	2	—	1	4	3	—	—	3	2	—	—	—	2	1	—	—
	11	W4554		—	—									—	—			—			
	12	W4554	2	4	24	1	—	1	1	4	—	1	1	—	—	—	1	2	1	—	—
	31	W3554	4	1	9	1	—	—	4	—	1	1	2	1	—	—	—	1			
Aug.	1	W3554	3	1	10	1	—	—	3	1	—	1	1	1	—	—	—	—	1		
	3	W4554	1	4	1	—	—	—	1	4	—	1	—	—	—	—	2	2	—	—	—
	8	W3554	1	—	1	—	—	—	1	—	—	—	1	—	—						
	16	W4554	1	3	—	—	—	1	—	3	—	—	1	—	—	—	1	2	—	—	—
	18	W5554	3	23	—	—	—	3	—	21	2	2	1	—	—	—	19	2	1	—	1
	19	W5554	4	38	—	—	—	4	—	37	1	3	1	—	—	—	28	9	1	—	—
	22	W4558	1	34	1	—	—	1	—	32	2	—	1	—	—	—	24	9	1	—	—

* Day set.

C-17. 1957, Etsuzan-maru (Japan)

Date	Statistical area	Catch/3000 ft					Maturity				Sockeye (ocean age)				Chum				
		Sockeye	Chum	Pink	Coho	Chinook	Sockeye		Chum		1	2	3	4	2	3	4	5	6
							I	*M*	*I*	*M*									
May 21	E 6550	23	14	—	—	—	3	20	0	14	—	3	19	1	—	—	12	2	
22	E 6550	31	9	—	—	—	0	31	0	9	—	2	29	—	—	—	5	3	1
25	E 6552	10	5	—	—	—	0	10	0	5	—	—	8	2	—	—	1	4	
26	E 6552	24	9	—	—	—	0	24	0	9	—	—	24	—	—	—	5	1	3
27	E 6550	10	30	3	—	—	0	10	0	30	—	2	8	—	—	3	10	12	6
31	E 6548	10	8	18	—	—	3	7	0	8	—	3	7	—	—	—	6	2	
June 1	E 6550	18	15	4	—	—	0	18	0	15	—	—	17	1	—	2	13	—	
5	E 7052	4	10	1	—	—	0	4	0	10	—	1	3	—	—	—	7	2	2
7	E 7552	12	6	13	—	—	1	11	5	1	—	3	9	—	—	3	3	1	
9	8052	38	16	102	—	—	0	38	14	2	—	12	26	—	—	9	7	—	
11	8052	21	2	2	—	—	0	21	2	0	—	8	13	—	—	—	2	—	
12	8052	82	18	50	—	—	0	82	14	4	—	36	46	—	—	7	11	—	
13	8052	54	6	114	—	6	3	51	5	1	—	21	33	—	—	1	5	—	
15	8054	178	1	36	—	—					—	39	139	—	—	—	—	—	1
21	W7054	30	1	14	—	—	0	30	0	1	—	18	9	2	—	—	1	—	
23	W7054	93	—	—	—	—	0	93			—	39	54	—	—	—	—	—	
24	W7056	116	8	—	—	—	0	116	0	8	—	48	68	—	—	—	7	1	
July 6	8054	75	78	12	—	—	75	0	76	2	72	2	1	—	62	12	5	—	
7	E 7556	19	43	23	—	—	19	0	43	0	14	5	—	—	31	8	2	2	
8	E 7556	13	72	13	—	—	12	1	61	11	2	10	1	—	27	35	9	1	
9	8056	3	98	3	—	—	3	0	91	7	—	3	—	—	34	51	5	7	
10	E 7556	10	62	6	—	—	8	2	62	0	6	1	2	—	48	12	3	—	
13	E 7052	32	27	28	—	—	27	5	22	5	8	18	6	—	15	7	3	3	
15	E 6052	14	43	10	3	—	3	11	40	3	—	5	7	1	27	11	5	—	
16	E 6052	12	38	31	3	—	3	9	27	11	3	4	5	—	13	14	8	3	
17	E 6052	36	49	11	—	—	21	15	48	1	10	16	10	—	30	11	8	—	
19	E 6052	22	30	14	3	—	10	12	23	7	8	3	10	1	20	1	5	4	
20	E 6052	30	17	14	1	—	19	11	11	6	2	17	11	—	5	8	4	—	
21	E 6052	13	16	6	6	—	2	11	16	0		5	6	—	13	2	2	—	
24	E 6050	—	10	—	—	—					Data lacking								
25	E 6050	13	34	24	8	—	3	10	34	0	3	8	3	—	30	2	2	—	
26	E 6050	13	13	25	3	—	4	9	10	3	1	6	6	—	10	—	3	—	
27	E 6052	3	24	3	10	—	2	1	12	12	—	2	2	—	10	1	10	1	2
28	E 6052	13	23	4	20	—	0	13	23	0	—	5	8	—	19	4	—	—	
29	E 6052	29	59	1	13	—	17	12	45	14	1	10	18	—	38	5	16	—	
30	E 6052	25	33	—	26	—	15	10	29	4	3	18	5	—	10	8	14	1	
31	E 6552	16	18	—	14	—	13	3	15	3	4	12	—	—	7	5	7	—	
Aug. 1	E 6552	11	9	1	33	1	11	0	7	2	—	9	2	—	7	1	1	—	

C-18. 1957, KANO-MARU (Japan)

Date		Statistical area	Catch/3000 ft					Maturity				Sockeye (ocean age)				Chum				
			Sockeye	Chum	Pink	Coho	Chinook	Sockeye		Chum		1	2	3	4	2	3	4	5	6
								I	*M*	*I*	*M*									
May	18	E 6548	22	12	18	—	—	3	19	0	12	—	11	11	—	—	1	8	1	2
	19	E 6548	32	21	4	—	—	1	31	5	16	—	8	24	—	—	1	13	4	4
	21	E 6548	28	15	6	—	—	0	28	3	12	2	5	21	—	—	—	9	6	—
	23	E 6548	18	3	—	—	—					Data lacking								
	24	E 6548	10	5	12	—	—	0	10	0	5	—	3	7	—	—	—	2	2	1
	25	E 7048	27	23	9	—	—	0	27	3	20	—	2	25	—	—	—	15	6	2
June	1	E 7048	13	13	19	—	—	2	11	5	8	—	2	11	—	—	—	12	1	—
	6	E 7548	16	7	38	—	—	2	14	0	7	—	9	7	—	—	—	7		
	8	E 7550	2	4	68	—	—	0	2	3	1	—	1	1	—	—	3	—	1	
	10	E 7548	10	3	56	—	—	10	0	2	1	10	—	—	—	—	3			
	11	E 7550	5	10	28	—	—	5	0	4	6	5	—	—	—	—	6	4	—	—
	12	8050	30	3	13	—	—	30	0	3	0	25	5	—	—	—	3			
	19	W7550	4	10	61	—	—	1	3	7	3	—	3	1	—	—	6	4	—	—
	20	W7550	2	5	45	—	—	1	1	3	2	—	1	1	—	—	4	1	—	—
	21	W7050	17	9	13	—	—	10	7	2	7	3	12	3	—	—	3	3	—	3
	22	W7050	10	3	10	—	—	8	2	0	3	—	9	1	—	—	3			
	24	W7550	10	23	22	—	—	7	3	18	5	3	4	2	—	5	13	5	—	—
	27	8054	32	16	65	—	—	0	32	14	2	—	8	24	—	—	11	2	2	—
	28	8054	9	1	173	—	—	2	7	0	1	—	3	6	—	—	1			
	29	8054	12	13	53	—	—	0	12	9	4	—	6	6	—	3	5	4	—	—
July	7	W6556	23	38	1	—	1	0	23	0	38	—	12	11	—	—	6	28	4	—
	8	W7056	3	3	2	2	—	3	0	1	2	3	—	—	—	—	3			
	15	E 6558	34	3	103	—	3	18	16	0	3	12	9	13	—	—	—	3		
	16	E 6558	48	49	156	—	—	46	2	42	7	32	9	7	—	30	12	5	—	2
	19	E 6052	20	38	15	—	—	2	18	34	4	—	6	14	—	30	3	5	—	—
	20	E 6052	11	23	8	2	—	6	5	16	7	3	5	1	—	15	3	5	—	—
	21	E 6052	22	23	9	—	—	13	9	17	6	4	8	11	—	10	7	3	2	—
	24	E 6050	17	41	5	—	3	9	8	38	3	9	1	7	—	33	4	2	3	—
	25	E 6052	13	39	13	13	—	7	6	32	7	—	7	6	—	24	3	9	3	—
	26	E 6050	5	32	23	9	—	0	5	28	4	—	—	3	2	26	1	5	—	—
	27	E 6050	30	28	13	8	—	18	12	22	6	2	20	5	2	15	2	12	—	—
	28	E 6052	22	32	1	13	1	3	19	27	5	2	5	15	—	17	7	8	—	—
	29	E 6052	16	27	1	3	—	3	13	25	2	1	4	11	—	15	6	7	—	—
	30	E 6052	17	19	—	4	—	14	3	17	2	1	11	5	—		Data lacking			
	31	E 6552	20	13	—	4	—	16	4	13	0	6	10	4	—	3	7	3	—	
Aug.	2	E 6552	8	33	—	8	1	6	2	26	7	—	5	3	—	6	7	19	1	
	4	E 6552	18	9	3	3	—	14	4	7	2	2	13	3	—	4	1	3	1	
	5	E 6552	32	13	—	5	—	29	3	12	1	7	23	2	—	5	4	5	-	
	6	E 6052	23	18	—	5	—	19	4	15	3	2	16	5	—	8	4	6	—	
	8	E 6052	30	40	—	1	—	28	2	36	4	5	16	8	1	33	2	3	2	—

C-19. 1957, Attu (U.S.)

Date	Statistical area	Catch/3000 ft					Maturity				Sockeye (ocean age)				Chum					
		Sockeye	Chum	Pink	Coho	Chinook	Sockeye		Chum		1	2	3	4	2	3	4	5	6	?
							I	*M*	*I*	*M*										
May 28	W7550	4	11	28	—	—	3	1	5	6	—	3	1	—	—	—	9	1	1	—
30	W7550	4	17	31	—	—	4	—	7	10	1	2	1	—	—	3	12	2	—	—
31	W7550	2	8	67	—	—	2	—	4	4	—	1	1	—	—	3	4	1	—	—
June 8	W7552	20	1	16	—	3	1	19	1	—	—	7	13	—	—	—	1	—	—	—
9	8052	18	3	19	—	2	2	17	1	2	1	8	9	—	—	—	1	1	1	—
10	W7552	19	4	14	—	1	—	19	2	2	—	13	6	—	—	1	2	1	—	—
15	W7556	80	6	17	—	+	1	79	—	6	—	17	62	1	—	1	4	1	—	—
17	W7556	65	7	45	—	1	1	64	1	6	—	13	52	—	—	1	5	1	—	—
18	W7056	58	4	4	—	1	—	58	1	3	—	19	39	—	—	—	2	2	—	—
19	W7056	31	1	—	—	—	—	31	—	1	—	5	26	—	—	—	1	—	—	
20	W7056	4	1	1	—	—	—	4	—	1	—	1	3	—	—	—	1	—	—	—
21	W7056	25	3	12	—	—	—	25	—	3	—	11	14	—	—	—	1	2	—	—
22	W7054	42	3	3	—	—	—	42	1	2	—	21	21	—	—	—	3	—	—	—
23	W7056	11	1	—	—	—	—	11	—	1	—	4	7	—	—	—	—	1	—	—
24	W7054	6	6	2	—	—	1	5	1	5	—	3	3	—	—	3	2	1	—	—
July 8	W6556	2	—	-	—	—	—	-	—	-	-	1	1	—	—	—			-	-
9	W6556	1	-	—	-	-	-	—	—	-	-	1	—	—			-		-	
10	W6556	6	3	—	—	—	—	6	1	2	—	3	3	—	—	1	2	—	—	—
15	W6054	27	28	5	1	1	22	5	27	1	15	9	3	—	1	19	5	1	—	2
17	W6052	32	12	—	+	2	31	1	12	—	9	22	1	—	1	7	3	1	—	—
19	W6050	4	33	+	3	+	3	1	33	—	1	2	1	—	21	11	1	—	—	—
21	W6550	2	17	—	1	+	2	—	16	1	1	1	—	—	4	10	3	—	—	—
24	W6552	50	76	1	2	—	46	4	75	1	33	16	1	—	14	48	9	1	—	4
25	W6552	6	15	9	1	—	—	6	14	1	1	3	2	—	1	6	8	—	—	—
27	W6556	1	3	+	3	—	—	1	2	1	—	1	—	—	1	1	1	—	—	—
28	W6556	1		-	-		—	1	-		—		1	-	-	-	-			
30	W6552	7	10	1	1	—	3	4	10	—	1	5	1	—	—	9	1	—	—	—
31	W6552	12	11	1	6	—	8	4	10	1	4	7	1	—	3	7	1	—	—	—
Aug. 9	W6550	7	47	—	—	—	5	2	47	—	3	4	—	—	9	31	6	1	—	—
11	W6552	1	19	1	1	—	1	—	18	1	—	1	—	—	4	12	2	1	—	—
14	W7054	1	—	—	+	—	—	1	—	—	—	—	1	—	—	—	—	—	—	—
15	W6554	2	1	1	-	-	1	1			-	1	1		-	1				
18	W6552	6	78	—	2	—	—	—	57	21	3	2	1	—	24	43	9	—	—	2
20	W6550	2	11	—	—	—	2	—	10	1	1	1	—	—	—	9	2	—	—	—
21	W6550	1	2	—	—	—	1	—	2	—	—	1	—	—	—	1	1	—	—	—
Sept. 8	W4058		5	-	-		-		1	4	-	-				3	2			

C-20. 1957, Paragon (U.S.)

Date		Statistical area	Catch/3000 ft					Maturity				Sockeye (ocean age)				Chum					
			Sockeye	Chum	Pink	Coho	Chinook	Sockeye		Chum		1	2	3	4	2	3	4	5	6	?
								I	*M*	*I*	*M*										
July	21	W7550	2	4	—	3	—	—	—	3	1	1	1	—	—	—	4	—			
	22	W7550	5	16	—	4	1	—	—	15	1	1	3	1	—	13	2	—	—	—	1
	24	W7552	1	6	+	1	—	—	—	6	—	—	1	—	—	1	3	2	—	—	—
	25	W7552	1	1	—	—	—	—	—	—	?	—	1	—	—	—	—	—	—	—	1
	27	W7556	1	3	—	—	—	—	—	3	—	—	1	—	—	—	1	2	—	—	—
	28	W7556	1	1	—	—	—	—	—	1	—	—	1	—	—	—	1	—	—	—	—
	30	W7552	1	4	1	1	—	—	—	3	1	—	1	—	—	1	2	1	—	—	—
	31	W7552	—	1	+	—	—	—	—	—	1	—	—		—	—	—	-	-	—	
Aug.	1	W7552	1	1	—	—	1	—	—	1	—	—	1	—	—	—	1		-		—
	6	8050	17	21	3	4	+	—	—	19	2	11	6	—	—	3	12	5	1	—	—
	7	8050	57	2	—	1	—	56	1	2	—	28	25	3	1	—	1	1	—	—	—
	8	W7548	22	19	—	2	6	22	—	18	1	3	18	1	—	1	14	2	2	—	—
	9	8050	49	15	+	+	2	49	—	15	—	14	34	1	—	3	9	2	—	—	1
	12	W7552	1	1	—	—	—	—	—	1	—	—	1	—	—	—	—	1	-		
	13	8054	—	2	—	—	—	—	—	1	1	—	—	—	—	—	1	1	—	—	—
	14	W7554	3	7	—	—	—	3	—	6	1	1	1	1	—	1	3	2	—	—	1
	16	W7552	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
	17	W7552	2	28	—	—	—	2	—	25	3	—	2	—	—	1	14	11	1	1	—
	18	8052	1	14	—	—	—	1	—	14	—	—	1	—	—	—	8	6	—	—	—
	20	8050	26	9	—	—	—	26	—	8	1	12	13	1	—	—	7	2	—	—	—
	21	8050	31	3	—	—	—	31	—	3	—	20	10	1	—	—	2	1	—	—	—
	22	8050	40	10	—	—	—	40	—	9	1	16	23	1	—	—	8	1	—	—	1
	23	8050	20	51	—	2	1	17	3	49	2	9	10	1	—	4	40	7	—	—	—
Sept.	8	W4050			—	—	—			—	—	-	—	—		—	—				
	10	W4050	—	—	—	—	—	—	—	—	—	—	—	—	-	-	-	—			
	12	W3050	—	—	—	—		-			—	—	—				-	-			

C-21. 1957, Pioneer (U.S.).

Date		Statistical area	Catch/3000 ft					Maturity				Sockeye (ocean age)				Chum					
			Sockeye	Chum	Pink	Coho	Chinook	Sockeye		Chum		1	2	3	4	2	3	4	5	6	7
								I	*M*	*I*	*M*										
June	10	E 7550	14	33	59	—	—	7	7	30	3	4	2	8	—	-	5	21	5	1	1
	11	E 7550	33	16	29	—	—	30	3	15	1	25	1	7	—	-	1	13	1	1	-
	12	E 7550	47	35	47	—	—	42	5	32	3	34	9	3	1	-	10	20	4	1	-
	14	E 7552	9	13	71	—	—	8	1	5	8	—	3	6	—	-	4	6	2	1	-
	20	E 7552	29	31	107	—	—	21	8	25	6	12	7	10	—	-	17	9	2	2	1
	22	8052	18	24	244	—	—	14	4	23	1	—	6	12	—	2	18	3	1	-	-
	29	W7556	2	17	62	—	—	1	1	12	5	—	1	1	—	-	7	9	1	-	—
	30	W7556	13	21	19	—	—	12	1	16	5	—	5	8	—	1	12	5	1	-	2
July	3	W7552	2	25	—	—	—	—	2	25	—	1	—	1	—	23	1	1	-	-	-
	4	W7552	3	25	2	—	—	2	1	25	—	1	1	1	—	23	2	—	-	-	-
	6	W7550	1	38	1	2	+	—	1	36	2	—	—	1	—	27	9	1	1	-	-
	7	W7550	—	50	+	3	—	—	—	49	1	—	—	—	—	33	13	2	-	-	2
	8	8050	15	63	3	3	1	14	1	61	1	3	11	1	—	40	20	3	-	-	-
	16	E 7556	5	24	4	—	—	—	—	23	1	3	1	1	—	21	1	1	-	-	1
	19	E 7552	3	169	1	—	—	—	—	167	2	1	1	1	—	131	24	3	-	-	11
	21	E 7550	1	31	—	2	—	—	1	31	—	—	1	-	-	31	1	-	-	-	-
	22	E 7550	6	26	—	15	+	—	—	25	1	2	3	1	—	25	1	—	-	-	-
	23	E 7552	2	19	1	3	—	1	1	17	2	—	1	1	—	12	4	2	1	-	-
	24	E 7552	1	118	+	1	+	—	1	117	1	—	—	1	-	113	5	-	-	-	-
	25	E 7554	2	31	+	—	+	—	—	31	—	1	—	1	—	25	1	1	-	-	4
	26	E 7554	1	22	1	—	—	—	1	21	1	—	—	1	—	16	5	1	-	-	-
	27	E 7556	4	69	+	1	—	—	—	68	1	1	2	1	—	62	4	3	1	-	-
	28	E 7556	2	28	—	1	—	—	—	27	1	—	1	1	—	13	9	5	1	-	-
	30	E 7552	—	18	1	1	—	—	—	17	1	—	—	—	—	12	4	2	-	-	-
Aug.	8	E 7550	13	9	—	3	—	13	—	8	1	2	10	1	—	-	6	2	-	-	1
	9	E 7550	8	8	—	1	1	8	—	7	1	1	6	1	—	1	4	3	-	-	-
	11	E 7552	32	15	1	—	—	31	1	13	2	27	4	1	—	1	9	4	-	-	1
	12	E 7552	42	35	1	—	—	41	1	33	2	27	14	1	—	4	19	11	1	-	-
	13	E 7554	3	22	+	—	—	3	—	22	—	1	1	1	—	11	7	4	-	-	-
	14	E 7556	15	29	—	—	—	15	—	29	—	5	8	2	—	24	4	1	-	—	—
	17	E 7552	54	43	1	1	—	53	1	41	2	38	15	1	—	11	19	11	1	—	1
	18	E 7552	30	26	+	—	—	30	—	25	1	23	7	—	—	2	14	9	1	—	—
	19	E 7550	62	18	1	5	4	62	—	17	1	13	48	1	—	1	10	6	1	—	—
	20	E 7550	29	5	—	—	—	—	—	4	1	7	21	1	—	-	2	3	-	-	—
	23	E 7550	42	49	1	+	1	—	—	48	1	17	24	1	—	3	19	24	1	1	1
	24	E 7552	6	16	—	+	—	25	—	15	1	3	2	1	—	1	10	3	1	-	1
Sept.	7	W5054	1	12	—	—	—	4	—	10	2	—	1	—	—	3	5	3	-	-	1

C-22. 1958, Fort Ross (Canada)

Date		Statistical area	Catch/3000 ft					Maturity				Sockeye (ocean age)					Chum				
			Sockeye	Chum	Pink	Coho	Chinook	Sockeye		Chum		1	2	3	4	?	2	3	4	5	?
								I	*M*	*I*	*M*										
May	17	W3550	1	1	1	1	—	—	1	1	—	—	1	—	—	—	—	1			
	19	W3550	—	—	—	—		—		—	—										
	24	W4550	10	2	1	1	1	7	3	—	2	1	7	1	—	1	—	1	1	—	—
	25	W4550	7	5	1	1	—	3	4	1	4	—	6	—	—	1	—	3	2	—	—
	27	W4550	17	9	3	—	—	12	5	2	7	1	15	—	—	1	—	4	3	1	1
June	7	W5054	27	5	—	—	—	—	27	—	5	—	16	10	—	1	—	2	2	1	—
	8	W5054	10	2	—	—	—	—	10	—	2	—	6	3	—	1	—	1	1	—	—
	9	W5054	6	5	—	—	—	—	6	—	5	—	2	3	—	1	—	2	2	—	1
	10	W5054	38	3	1	—	—	—	38	—	3	1	21	15	—	1	—	2	1	—	—
	15	W5554	42	3	1	—	—	2	40	—	3	2	23	12	—	5	—	2	—	1	
	16	W5554	16	1	1	—	—	1	15	—	1	2	9	3	—	2	—	1			
	23	W5550	11	5	3	—	—	6	5	3	2	6	4	—	—	1	—	2	2	—	1
	24	W5550	30	15	2	—	1	20	10	15	—	14	13	1	1	1	—	11	3	1	—
	25	W5550	19	6	3	—	1	12	7	6	—	8	10	1	—	—	—	4	2	—	—
	26	W5550	—	—	—	—		—		—		—			—			—			
July	26	W4550	1	—	—	—	—	—	1	—	—	—	1	—	—		—				
Aug.	1	W5550	1	29	—	—	—	1	—	29	—	1	—	—	—	—	5	20	2	—	2
	15	W5554	2	17	1	2	—	1	1	12	5	—	2	—	—	—	8	8	1	—	—
	18	W4554	—	1	—	—	—	—	—	—	1	—	—	—	—	—	—	1			

C-23. 1958, Key West II (Canada)

Date		Statistical area	Catch/3000 ft					Maturity				Sockeye (ocean age)					Chum				
			Sockeye	Chum	Pink	Coho	Chinook	Sockeye		Chum		1	2	3	4	?	2	3	4	5	?
								I	*M*	*I*	*M*										
May	11	W3050	1	—	1	—	—	1	—	—	—	—	1	—	—	—	—	—	—	—	—
	17	W3550	1	—	1	2	—	—	1	—	—	—	—	—	—	—	—	1			
	18	W3550	1	13	2	3	—	—	1	11	2	—	1	—	—	—	1	10	1	—	1
	19	W3550	1	1	1	1	—	—	—	1	—	—	1	—	—	—	—	1	—	—	
	28	W3050	1	3	2	1	—	—	1	1	2	1	—	—	—	—	1	1	1	—	—
June	1	W4554	5	3	1	1	—	1	4	—	3	—	3	1	1	—	—	1	2	—	—
	2	W4554	5	1	1	—	—	1	4	—	1	—	4	1	—	—	—	1	—	—	—
	4	W4558	40	9	1	—	—	1	39	1	8	—	14	24	1	1	—	3	5	1	—
	5	W4558	49	6	10	1	—	7	42	—	6	1	19	28	—	1	—	—	5	1	—
	13	W3554	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
	14	W3554	1	—	—	—	—	—	1	—	—	—	—	1	—	—	—	—	—	—	—
	15	W3554	11	7	21	8	—	6	5	4	3	3	3	1	—	4	5	—	1	—	1
	16	W3554	1	2	3	4	—	—	1	1	1	—	1	—	—	—	1	—	1	—	
Aug.	23	W4558	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

C-24. 1958, KANO-MARU (Japan)

Date	Statistical area	Catch/3000 ft Sockeye	Chum	Pink	Coho	Chinook
May 19	E 5546	+	7	—	—	—
21	E 5548	1	19	—	—	—
23	E 5550	--	10	—	—	—
24	E 6052	1	8	+	—	+
27	E 6052	1	3	+	—	—
28	E 6052	×	×	×	×	×
June 1	E 6052	2	2	—	—	—
2	E 6054	8	7	1	—	—
4	E 6054	7	6	1	—	—
5	E 6056	5	1	3	—	+
6	E 6556	5	2	2	—	+
7	E 6556	2	3	3	—	+
8	E 6558	3	1	+	—	—
10	E 6558	4	1	3	—	+
11	E 7058	3	1	1	—	+
12	E 7058	2	+	1	—	+
13	E 7058	4	2	2	—	+
17	E 6558	10	2	22	—	—
18	E 6558	6	1	10	—	—
19	E 6558	7	4	10	—	—
20	E 6558	4	3	16	—	1
21	E 6558	3	4	32	—	2
June 22	E 6558	2	9	10	—	—
25	E 6558	2	17	30	—	2
26	E 6558	2	2	61	—	—
30	E 6056	2	5	8	—	+
July 19	E 5046	--	7	26	1	—
20	E 5546	19	2	36	1	—
29	E 6054	66	11	2	1	—
31	E 7058	34	82	+	—	1
Aug. 2	E 6558	44	40	—	—	—
3	E 6558	71	50	—	+	—
5	E 6558	31	43	—	1	+
6	E 6558	32	26	+	+	—
8	E 7058	32	57	+	1	—
9	E 7056	29	26	—	—	—
10	E 6556	50	25	—	—	—
11	E 6556	15	12	—	—	—
12	E 6556	4	2	—	+	—
13	E 6554	11	23	+	+	—
14	E 7056	27	45	+	+	+
15	E 7054	10	11	—	—	—
16	E 6554	3	6	—	—	—

× Weighted value not available since catches by gillnets of varying mesh sizes were not recorded.

C-25. 1958, WAKASHIO-MARU (Japan)

Date	Statistical area	Catch/3000 ft Sockeye	Chum	Pink	Coho	Chinook
May 20	8050	2	7	1	—	—
24	8050	5	8	6	—	+
27	W7550	3	1	7	—	—
28	W7550	4	5	3	—	—
30	W7050	2	3	+	—	—
June 1	W7552	4	6	3	—	—
2	W7552	12	6	4	—	1
3	W7552	7	+	+	—	1
4	W7552	4	1	1	—	4
8	8052	15	1	1	—	+
9	8052	2	1	2	—	--
10	8052	3	3	1	—	—
11	E 7552	1	3	2	—	—
12	E 7552	2	1	+	—	—
13	E 7552	1	6	1	—	—
14	E 7052	2	26	2	—	+
15	E 7054	3	13	3	—	—
18	E 7556	16	4	2	—	5
19	E 7556	6	2	4	—	12
22	W7556	11	2	1	—	4
23	8056	5	35	1	—	—
24	8054	3	7	1	—	1
25	8054	1	21	1	—	+
26	E 7556	1	21	1	—	+
June 27	E 7556	3	14	2	—	+
29	E 7056	3	65	1	—	1
July 1	E 7056	1	6	2	—	1
2	E 7056	2	10	2	—	—
19	E 5546	—	2	72	2	—
20	E 5546	—	1	22	4	—
25	E 6552	47	33	+	4	1
29	E 7052	35	17	+	10	+
30	E 7052	20	4	—	1	—
31	E 7054	4	19	+	1	—
Aug. 1	E 6554	80	10	--	+	—
2	E 6552	26	10	+	2	—
5	E 6554	25	10	+	1	—
6	E 6554	44	12	+	5	+
7	E 6054	17	3	—	5	—
8	E 6054	69	35	+	1	+
9	E 6054	48	31	1	7	—
10	E 6052	15	16	+	6	—
11	E 6052	8	11	—	2	—
13	E 6552	26	5	—	5	—
14	E 6552	12	7	+	1	—
15	E 6052	8	8	—	3	+
17	E 6050	27	3	+	5	—
18	E 5550	15	2	+	6	—

C-26. 1958, Attu (U.S.)

Date	Statistical area	Catch/3000 ft					Maturity				Sockeye (ocean age)				Chum					
		Sockeye	Chum	Pink	Coho	Chinook	Sockeye		Chum		1	2	3	4	2	3	4	5	6	?
							I	*M*	*I*	*M*										
May 28	8050	5	3	1	—	—	1	4	2	1	1	1	3	—	—	1	1	1	—	—
29	8050	3	9	1	—	—	1	2	3	6	—	2	1	—	—	—	5	3	1	—
31	8048	3	11	5	—	—	1	2	5	6	—	2	1	—	—	—	9	1	1	—
June 1	E 7548	1	6	—	—	—	—	—	2	4	—	1	—	—	—	—	2	3	—	1
8	E 7552	5	11	4	—	—	2	3	5	6	—	2	3	—	—	1	7	2	1	—
10	8054	3	2	2	—	—	1	2	1	1	—	1	2	—	—	—	1	—	—	1
17	W7552	20	12	8	—	1	1	19	1	11	1	10	9	—	—	7	4	1	—	—
18	W7052	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—			
24	W7054	1	2	—	—	—	—	1	—	2	—	1	—	—	—	1	1	—	—	—
25	W7054	32	6	1	—	—	5	27	2	4	5	19	8	—	1	2	2	1	—	—
26	W7554	9	8	1	—	1	1	8	2	6	1	5	3	—	—	5	2	1	—	—
27	W7056	2	1	—	—	—	—	2	?	?	—	1	1	—	—	—	—	—	—	1
28	W7056	2	—	—	—	—	—	2	—	—	—	1	1	—	—	—	—	-		
30	W7554	1	2	—	—	+	—	1	1	1	—	—	1	—	—	2	—	—	—	—
July 1	W7552	—	2	1	—	—	—	—	1	1	—	—	—	—	—	2	—	—	-	
2	W7552	3	1	—	—	1	1	2	1	—	—	2	1	—	—	1	—	—	—	—
11	8052	—	5	—	—	—	—	—	4	1	—	—	—	—	1	1	1	1	—	1
12	8052	6	8	—	—	—	4	2	7	1	3	2	1	—	2	5	—	—	—	1
13	8052	1	32	—	—	—	—	—	31	1	—	1	—	—	25	5	1	—	—	1
14	8052	13	187	1	—	—	13	—	185	2	11	2	—	—	140	41	3	1	—	2
15	E 7554	11	25	1	—	—	11	—	24	1	9	1	1	—	16	8	1	—	—	—
16	E 7554	1	65	—	—	—	1	—	63	2	—	1	—	—	52	9	2	1	—	1
17	E 7554	4	113	—	—	—	3	1	112	1	2	1	1	—	95	11	1	—	—	6
18	E 7554	8	95	—	—	+	7	1	94	1	6	1	1	—	80	8	5	—	—	2
19	E 7554	3	77	—	—	—	3	—	77	—	2	1	—	—	70	4	—	—	—	3
20	E 7054	1	43	—	+	1	1	—	41	2	1	—	—	—	37	2	2	1	—	1
21	E 7054	3	34	1	1	—	3	—	32	2	1	1	1	—	15	17	2	—	—	—
22	E 7052	2	10	—	—	—	1	1	8	2	1	—	1	—	1	6	2	—	—	1
Aug. 5	W7552	5	24	—	—	—	4	1	24	—	3	1	1	—	1	20	2	1	—	—
6	W7554	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
7	W7554	7	5	—	—	—	7	—	5	—	3	3	1	—	—	4	1	—	—	—
10	W7552	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
17	W6552	15	23	—	—	—	15	—	22	1	4	10	1	—	6	14	2	—	—	1
18	W6550	12	7	—	—	1	12	—	6	1	4	7	1	—	1	6	—	—	—	—
19	W6550	9	7	—	—	—	9	—	6	1	1	8	—	—	2	4	1	—	—	—
25	W5052	—	1	—	—	—	—	—	—	1	—	—	—	—	—	1	—	—	—	—
27	W4054	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

C-27. 1958, Pioneer (U.S.)

Date	Statistical area	Catch/3000 ft					Maturity				Sockeye (ocean age)				Chum					
		Sockeye	Chum	Pink	Coho	Chinook	Sockeye		Chum		1	2	3	4	2	3	4	5	6	?
							I	*M*	*I*	*M*										
May 28	8052	2	2	3	—	—	—	—	—	2	—	—	1	1	—	—	1	1	—	—
29	E 7552	2	—	+	—	—	—	2	—	—	—	—	2	—	—	—	—	—	—	—
31	E 7054	3	1	1	—	—	—	3	—	1	—	1	1	1	—	—	1	—	—	—
June 1	E 7054	7	2	1	—	2	1	6	—	2	—	1	5	1	—	—	1	1	—	—
2	E 7052	6	9	+	—	—	—	6	1	8	—	1	4	1	—	—	6	2	1	—
8	E 7050	4	15	7	—	1	2	2	3	12	—	2	2	—	1	11	1	—	2[1]	—
17	8052	1	20	2	+	+	—	1	14	6	—	1	—	—	1	4	14	1	—	—
18	8054	4	17	3	—	+	—	4	11	6	—	1	3	—	2	12	2	—	—	—
22	E 7554	5	25	1	—	1	1	4	14	11	1	2	2	—	—	1	17	1	2	4
30	8050	27	61	—	1	—	26	1	59	2	25	1	1	—	49	7	1	1	—	3
July 6	8050	17	28	1	—	—	15	2	28	—	11	4	2	—	11	13	—	—	—	4
7	W7550	8	99	2	+	—	7	1	98	1	4	4	—	—	29	63	2	—	—	5
8	W7548	4	8	1	1	—	4	—	8	—	3	1	—	—	5	3	—	—	—	—
10	8050	2	37	+	3	—	1	1	35	2	—	1	1	—	23	4	3	—	—	7
12	E 7550	29	21	+	1	—	26	3	20	1	23	5	1	—	19	—	1	—	—	1
13	E 7550	4	9	+	3	—	4	—	8	1	3	1	—	—	4	4	1	—	—	—
14	E 7548	2	6	1	15	—	2	—	4	2	1	1	—	—	4	1	1	—	—	—
15	E 7548	3	10	1	4	—	3	—	9	1	1	2	—	—	8	1	1	—	—	—
16	E 7550	7	18	—	2	—	6	1	16	2	4	2	1	—	15	1	1	—	—	1
17	E 7550	3	7	—	5	—	1	2	3	4	—	2	1	—	1	3	3	—	—	—
18	E 7552	29	14	1	2	—	27	2	12	2	24	2	3	—	3	9	1	1	—	—
19	E 7552	1	82	—	2	—	1	—	81	1	1	—	—	—	73	7	1	—	—	1
20	E 7552	—	21	1	1	—	—	—	19	2	—	—	—	—	13	7	1	—	—	—
21	E 7552	3	88	1	2	—	3	—	87	1	2	1	—	—	57	28	2	—	—	1
22	E 7552	1	4	—	—	—	1	—	3	1	1	—	—	—	1	1	1	—	—	1
24	E 7552	—	56	1	+	—	—	—	53	3	—	—	—	—	22	29	4	—	—	1
25	8052	—	75	1	5	—	—	—	74	1	—	—	—	—	27	44	2	1	—	1
26	8052	—	2	—	—	—	—	—	1	1	—	—	—	—	—	1	1	—	—	—
27	8052	3	28	1	2	1	2	1	27	1	—	2	1	—	3	21	3	—	—	1
28	8052					—				-	—									
Aug. 5	W7550	34	5	—	7	1	32	2	5	—	27	5	2	—	1	4	—	—	—	—
6	W7550	41	11	—	3	2	40	1	11	—	31	9	1	—	1	8	1	—	—	1
7	W7548	15	15	1	2	—	15	—	14	1	9	5	1	—	2	11	1	—	—	1
9	W7048	5	15	—	1	—	5	—	14	1	—	4	1	—	1	11	1	1	—	1
10	W7050	11	25	—	—	+	11	—	25	—	1	8	1	1	3	18	3	—	—	1
11	W7050	23	22	—	—	+	22	1	22	—	15	8	—	—	11	7	—	—	—	4
15	W7052	14	127	1	7	1	13	1	124	3	9	4	1	—	40	55	7	—	—	25
19	W6054	—	2	—	1	—	—	—	2	—	—	—	—	—	1	1	—	—	—	—
20	W6052	2	12	—	1	+	1	1	12	—	—	1	1	—	5	5	1	—	—	1
25	W5048	—	—	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
27	W4050					-	-						-							

[1] One 6-year-old, one 7-year-old.

C-28. 1959, Fort Ross (Canada)

Date	Statistical area	Catch/3000 ft					Maturity				Sockeye (ocean age)					Chum				
		Sockeye	Chum	Pink	Coho	Chinook	Sockeye		Chum		1	2	3	4	?	2	3	4	5	?
							I	*M*	*I*	*M*										
May 17	W4554	8	6	—	—	—	—	8	—	6	—	3	5	—	—	—	—	3	3	—
18	W4554	23	—	—	—	—	3	20	—	—	10	4	8	—	1					
19	W4554	18	—	1	—	—	4	14	—	—	5	3	9	—	1					
20	W4554	3	5	—	—	—	—	3	—	5	—	—	3	—	—	—	3	2	—	—
21	W4554	23	23	—	—	—	3	20	5	18	3	10	10	—	—	—	11	9	2	1
26	W5054	11	3	3	—	—	—	11	—	3	—	8	—	—	3	—	—	3		
27	W5054	13	2	—	—	—	—	13	—	2	—	9	4	—	—	—	1	1	—	—
28	W5054	9	—	—	—	—	—	9	—	—	—	5	4							
June 10	W5554	21	6	—	—	—	7	14	3	3	—	21	—	—	—	—	1	5	—	—
11	W5554	10	—	6	1	—	4	6	—	—	—	7	3							
12	W5554	14	—	3	—	—	5	9	—	—	—	6	8							
July 5	W3550	15	—	—	—	—	—	15	—	—	—	8	5	—	2	—	—	—	—	
6	W3550	5	—	—	—	—	—	5	—	—	—	3	2			—				
7	W3550	4	—	—	—	—	—	4	—	—	—	1	3							
10	W3550	6	—	3	1	—	—	6	—	—	—	2	4							
11	W3550	9	—	—	—	—	—	9	—	—	—	7	2							
15[1]	W4552	14	13	5	—	—	—	14	11	2	—	8	3	3	—	8	5	—	—	—
18	W4552	6	3	2	—	—	—	6	3	—	—	6	—	—	—	3	—	—	—	—
19	W4552	14	2	4	—	—	—	14	2	—	—	14	—	—	—	—	2			
20	W4552	1	5	1	—	—	—	1	5	1	—	1	—	—	—	—	5			
21	W4552	5	9	4	—	—	3	2	4	5	3	—	2	—	—	2	7	—	—	—
25	W5554	20	3	3	—	—	17	3	3	—	11	9	—	—	—	—	3			
26	W5554	18	22	4	—	—	13	5	20	2	10	7	—	—	1	—	22	—	—	
Aug. 1	W5554	4	1	1	—	—	—	4	1	—	—	3	—	—	1	—	—	—	—	1
7	W4052	3	1	—	—	—	—	3	—	1	—	2	—	—	1	—	—	1		

[1] Catch data questionable. Data have not been considered.

C-29. 1959, Key West II (Canada)

Date	Statistical area	Catch/3000 ft					Maturity				Sockeye (ocean age)					Chum				
		Sockeye	Chum	Pink	Coho	Chinook	Sockeye		Chum		1	2	3	4	?	2	3	4	5	?
							I	*M*	*I*	*M*										
May 18	W4550	9	3	1	—	—	6	3	1	2	2	5	2	—	—	—	2	1	—	—
19	W4550	12	1	5	1	—	8	4	1	—	2	7	2	1	—	—	1	—	—	
21	W4554	20	5	1	—	—	1	19	—	5	—	9	9	—	2	—	1	4	—	—
22	W4554	5	1	—	—	—	—	5	—	1	1	3	1	—	—	—	—	1	—	—
23	W4554	5	1	1	—	—	5	—	—	1	4	—	—	—	1	—	—	1	—	—
25	W4558	30	5	—	—	—	1	29	—	5	1	15	14	—	—	—	1	3	1	—
26[1]	W4558	2	1	—	—	—	—	2	—	1	—	1	1	—	—	—	—	1	—	—
June 10	W5554	25	5	1	—	—	5	20	1	4	4	11	4	—	6	—	2	2	1	—
12	W5554	80	40	3	—	—	8	72	1	39	4	20	4	—	52	—	15	14	—	11
14	W6052	4	7	14	—	—	1	3	1	6	1	2	1	—	—	—	2	2	—	3
24	W6052	9	3	8	—	—	4	5	1	2	4	3	2	—	—	1	1	1	—	—
25	W6052	28	12	25	—	—	20	8	3	9	14	9	3	—	2	—	8	3	—	1
27	W6050	29	45	11	—	—	26	3	42	3	19	7	1	—	2	—	13	19	1	12
28	W6050	36	—	19	—	—	34	2	—	—	16	3	—	—	17	—	—	—	—	—
29	W5550	86	22	2	1	—	86	—	20	2	56	3	—	—	27	—	12	5	—	5
July 17	W3550	2	—	—	—	—	—	2	—	—	—	1	1	—	—	—	—	—	—	—
18	W3550	1	—	—	—	—	—	1	—	—	—	1	—	—	—	—	—	—	—	—
19	W3550	1	—	3	—	—	—	1	—	—	—	—	1	—	—	—	—	—	—	—
24	W3550	1	—	—	—	—	—	1	—	—	—	1	—	—	—	—	—	—	—	—
25	W3550	6	1	1	—	—	—	6	—	1	—	5	1	—	—	—	—	—	—	1

[1] Catch data questionable. Data have not been considered.

C-30. 1959, KANO-MARU (Japan)

Date	Statistical area	Catch/3000 ft					Maturity				Sockeye ocean age				Chum				
		Sockeye	Chum	Pink	Coho	Chinook	Sockeye		Chum		1	2	3	4	2	3	4	5	6
							I	*M*	*I*	M									
May 25	8050	5	35	1	-		0	5	1	34	—	1	4	—	—	1	33	1	—
26	8050	16	36	1	-	—	0	14	0	36	1	9	4	—	—	—	32	4	—
27	8050	14	18	10	—	-	1	13	0	18	1	10	4	—	—	1	16	1	—
28	W7550	6	23	13	—	1	1	5	0	23	1	4	1	—	—	1	20	2	—
29	W7550	5	45	10	-	1	1	4	0	45	—	4	1	—	—	2	37	6	—
June 1	W7050	4	4	11			1	3	0	4		4	—	—	—	4	—	—	—
3	W7552	21	22	1		1	7	14	0	22	6	10	5	—	—	—	20	2	—
4	W7552	22	3	-	—	6	19	3	1	2	19	2	1	—	—	—	2	—	1
5	8052	10	11	8	-		1	9	0	11	1	7	1	—	—	1	10	—	—
8	8052	2	11	2		—	0	2	6	5	—	1	1	—	—	—	11	—	—
10	E7552	16	3	3	-		1	15	1	2	—	12	4	—	—	—	2	1	—
13	E7552	3	12	8		1	0	3	1	11	—	2	1	—	—	1	10	1	—
15	W7556	22		3		2	1	21			2	16	4	—	—	—	-		
16	8056	2	8	1	—	1	0	2	0	8	—	1	1	—	—	—	7	1	—
18	8056	14	4	9		-	0	14	0	4	—	11	3	—	—	—	4	—	—
19	E7556	11	3	3	-		2	9			2	6	3	—	—	—	3	—	—
20	E7556	11	23	16		-	6	5	7	16	4	2	5	—	—	—	21	2	—
21	E7556	13	6	34		2	1	12	0	6	—	8	5	—	—	—	4	2	—
22	E7056	14	26	10		1	1	13	9	17	—	9	5	—	—	1	24	1	—
July 9	E4546		4	64					0	4	—		-	—		1	2	1	—
11	E5046		1	15	1				0	1	—	—	—	—	—	—	1	—	—
14	E5048	-	4	44	1				1	3	—	—	—	—	1	—	2	1	—
15	E5048	-	2	25	3	1			0	2	- -		—	—	—	—	2	—	—
16	E5050		4	46	1				1	3	—	—	—	—	1	1	2	—	—
17	E5052	- -	16	28	1				8	8	—	—	—	—	7	1	6	1	—
18	E5052	1	99	26	1				46	53	1	—	—	—	39	10	49	2	—
20	E5052	6	28	132	3		0	6	3	25	—	1	5	—	2	1	24	1	—
21	E5052	6	34	86	2		0	6	19	15	1	3	3	—	12	9	12	2	—
27	8058	3	8		1	1	3	0	8	0	—	3	—	—	5	3	—	—	—
28	E7558	11	41	2	—		11	0	40	1	2	9	—	—	10	10	20	—	—
29	E7558	6	38	5	1		6	0	35	3	2	4	—	—	8	6	23	1	—
30	E7558	5	20	6	-		5	0	19	1	—	4	1	—	6	6	6	1	—
31	E7058	6	84	19			6	0	76	8	1	4	1	—	34	27	23	—	—
Aug. 1	E7058	52	56	9	1	1	52	0	45	11	16	32	4	—	33	14	8	1	—
2	E7056	28	29	5			28	0	17	12	—	27	1	—	4	12	12	1	—
3	E7056	11	6	1			11	0	5	1	3	9	—	—	1	4	1	—	—
4	E7054	1	3				1	0	2	1	—	1	1	—	1	1	2	—	—
5	E7054	13	40	1	1		13	0	30	10	8	5	—	—	23	1	16	—	—
7	E6556	10	14	1	1		10	0	12	2	6	4	—	—	2	5	6	—	—
8	E6556	12	9	1		1	12	0	8	1	9	3	—	—	5	1	2	1	—
9	E6558	54	11	1			54	0	9	2	44	8	2	—	9	—	2	—	—
10	E6558	13	10	5	3		12	1	6	4	10	3	1	—	4	2	4	—	—
11	E6558	6	12	1	1		6	0	3	9	6	—	—	—	—	1	10	1	—
12	E6558	15	16				14	1	10	6	12	2	1	—	6	3	6	—	—
13	E6558	18	12	1	2		17	1	12	0	14	4	1	—	2	2	8	—	—
14	E6558	36	27	1	1		35	1	27	0	24	11	1	—	18	8	1	—	—
16	E6558	18	17		3		18	0	16	1	16	2	—	—	—	9	8	—	—
17	E6054	9	2	1	9		8	1	0	2	4	4	1	—	—	—	2	—	—
18	E6054	15	4	1	8	1	15	0	1	3	1	13	2	—	—	1	3	—	—
19	E6054	17	6		15	—	16	1	5	1	4	13	—	—	1	5	—	—	—
20	E6554	32	14	1	5	2	32	0	10	4	3	26	3	—	3	3	8	—	—
21	E6552	38	13		5	4	38	0	13	0	1	35	1	—	—	7	6	—	—
22	E6052	12	24		2	1	12	0	22	2	—	12	—	—	2	10	12	—	—

C-31. 1959, Pioneer (U.S.)

Date	Statistical area	Catch/3000 ft					Maturity				Sockeye (ocean age)				Chum					
		Sockeye	Chum	Pink	Coho	Chinook	Sockeye		Chum		1	2	3	4	2	3	4	5	6	?
							I	*M*	*I*	*M*										
Apr. 24	W5556	1	1	—	—	—	—	1	—	1	—	1	—	—	—	—	1	—	—	—
27	W5554	6	2	—	—	—	—	6	—	2	—	1	5				2			
May 20	E 7550	5	29	—	—	—	—	5	26	3	—	4	1	—	1	1	26	1	—	—
22	E 7550	11	76	—	—	+	1	10	10	66	—	6	4	1	—	1	66	4	—	5
23	E 7550	4	4	—	—	—	—	4	1	3	—	2	2				3	1		
24	E 7548	5	24	—	—	—	1	4	9	15	—	4	1	—	1	22	1	—	—	—
25	E 7548	5	72	12	—	1	2	3	51	21	—	4	1	—	—	1	33	1	—	37
27	E 7048	3	4	—	—	—	—	3	2	2	—	2	1	—	—	1	3	—	—	—
28	E 7050	5	3	—	—	+	—	5	1	2	—	1	4				3			
June 3	E 7052	2	3	—	—	+	1	2	1	2	—	1	1				3	—	—	—
4	E 7052	5	4	1	—	—	—	5	—	4	—	2	3				4	—	—	—
5	E 7052	9	4	—	—	—	—	9	1	3	—	3	6				3	1		
6	E 7054	12	5	—	—	—	—	12	—	5	—	5	6	1	—	—	5			
8	E 7054	14	4	—	—	1	—	14	1	3	—	5	9	—	—	—	3	1	—	—
13	8052	13	8	8	—	—	—	13	5	3	—	11	2	—	—	—	7	—	—	1
22	8052	7	2	9	—	—	1	6	1	1	—	4	3	—	—	1	1	—	—	—
23	E 7552	14	44	97	—	—	2	12	32	12	—	11	3	—	—	30	12	1	—	1
24	8054	3	5	38	—	+	—	3	3	2	—	2	1	—	—	1	4	—		
25	8054	10	3	29	—	—	1	9	2	1	1	7	2	—	—	—	2	1	—	—
26	8056	22	6	6	—	—	1	21	5	1	—	18	4	—	—	1	5	—	—	—
27	8056	24	13	10	—	+	1	23	9	4	1	18	5	—	—	1	11	—	—	1
28	8058	10	22	203	—	2	7	3	7	15	4	5	1	—	—	1	17	4		
30	8060	6	19	54	—	2	2	4	6	13	—	5	1	—	—	—	18	1		
July 4	E 7558	11	28	105	—	1	10	1	17	11	1	9	1	—	—	1	19	1	—	7
15	E 7554	5	47	73	+	—	4	1	44	3	1	3	1	—	33	9	4	—	—	1
16	E 7554	3	13	3	—	—	2	1	12	1	1	1	1	—	10	1	2	—	—	—
19	E 7050	7	4	1	3	+	5	2	3	1	3	3	1	—	1	1	1	—	—	1
22	E 7550	15	2	1	3	+	14	1	1	1	7	8	—	—	—	1	1	—		
23	E 7550	18	5	+	14	+	15	3	3	2	12	6	—	—	2	1	2	—		
27	8050	112	41	5	9	—	107	5	39	2	98	13	1	—	16	17	4	1	—	3
28	8050	81	13	1	2	+	79	2	13	—	75	5	1	—	4	7	1	—		
29	8050	225	36	4	11	1	207	18	36	—	201	22	2	—	4	29	2	—	—	1
Aug. 5	W7550	127	4	—	1	—	125	2	4	—	104	22	1	—	—	2	1	—		
6	W7550	97	13	+	1	+	95	2	13	—	62	34	1	—	11	1	—	1	—	—
7	W7548	15	9	—	1	1	15	—	9	—	14	1	—	—	—	7	1	—	—	1
9	W7548	1	3	—	—	—	1	—	3	—	—	1				1	1	—	—	1
12	W7548	1	3	—	—	—	1	—	3	—	—	1			—	2	1	—		

C-32. 1959, Tordenskjold (U.S.)

Date	Statistical area	Catch/3000 ft					Maturity				Sockeye (ocean age)				Chum					
		Sockeye	Chum	Pink	Coho	Chinook	Sockeye		Chum		1	2	3	4	2	3	4	5	6	7
							I	*M*	*I*	*M*										
May 25	W7052	3	19	2	—	—	—	3	—	19	—	3	-	-		1	13	1	—	1
26	W7052	1	18	—	—	1	—	1	—	18	—	1		--			17	1	—	—
27	W7050	20	3	2	—	—	1	19	—	3	—	14	6	—	-		3		—	—
28	W7550	25	10	4	—	1	—	25	—	10	—	20	5	—			9	—	—	1
June 2	8050	17	22	2	—	—	1	16	6	16	1	14	2	—		1	18	1		2
3	8048	2	12	1	—	+	—	2	6	6	—	1	1	—		1	9	1		1
4	8048	2	21	23	—	—	2	—	12	9	1	1	—	—		2	13	1		5
7	8048	4	5	16	—	—	3	1	3	2	—	3	1	—			3			2
12	8050	25	10	7	—	—	6	19	3	7	5	16	4	—		1	2	1		6
14	8050	9	3	2	—	—	—	9	2	1	—	5	4	—			2	1		1
15	8050	47	16	21	—	—	1	46	11	5	1	34	12	—		4	10	1		1
21	W7552	8	6	28	—	—	1	7	3	3	1	6	1	—		1	4			1
22	8054	20	7	21	—	—	—	20	4	3	1	9	9	1		1	5			1
23	8054	15	8	113	—	+	—	15	2	6	—	11	4	—		1	5			2
24	8056	36	10	43	—	3	1	35	2	8	5	25	6	—		1	9			—
25	W7556	39	4	8	—	3	1	38	1	3	—	31	8				4	-	-	
27	W7058	8	16	12	—	1	—	8	—	16	—	7	1	—	-	8	7			1
28	W7058	24	3	2	—	—	—	24	—	3	—	21	3	—		1	1			1
29	W7556	2	—	—	—	—	—	2	—	—	—	1	1	—			—			
30	W7054	36	10	10	—	—	—	36	3	7	1	27	8	—		2	5	1	-	2
July 1	W7554	3	2	1	—	—	—	3	1	1	—	2	1	—		1	1	1		1
2	W7552	2	5	8	—	+	—	2	2	3	—	1	1	—		3	2			
3	W7052	3	12	23	+	—	—	3	10	2	—	2	1	—		6	6			
4	W7052	88	18	14	+	—	81	7	17	1	66	21	1	—		11	5	1		1
5	W7050	15	20	21	+	—	9	6	20	—	2	11	2	—		16	3		—	1
11	W6552	180	126	9	—	—	144	36	123	3	160	17	3	—		49	10	—	—	67
12	W6552	101	8	4	+	—	91	10	7	1	81	19	1	—		6	1	—		1
13	W6552	53	7	2	+	—	51	2	6	1	34	18	1	—	1	3	2			1
15	W6550	9	86	1	2	+	8	1	86	—	5	3	1	—	4	44	3	-	—	35
16	W6548	2	31	—	1	2	2	—	31	—	1	1	—	—	1	26	2	—	—	2
17	W7048	1	8	—	4	—	1	—	8	—	—	1	—	—	1	6	1	—	—	
19	W6546	1	17	—	2	+	—	—	17	—	1	—	—	—	4	12	1	—	—	
20	W6048	1	9	—	2	1	1	—	9	—	—	1	—		2	5	1	—	—	1
21	W6048	5	14	—	1	—	4	1	14	—	—	4	1	—	5	7	1	—	—	1
22	W6548	14	51	1	2	+	13	1	50	1	5	8	1	—	30	15	1	—		5
23	W6050	30	44	4	1	1	29	1	43	1	16	13	1	—	16	17	2			9
24	W6050	107	21	3	3	—	100	7	21	—	93	13	1	—	11	8	1			1
25	W6052	23	49	21	1	+	21	2	47	2	20	2	1	—	1	11	2			5
26	W6052	33	10	14	1	+	31	3	9	1	31	2	—	—	1	8	1	1		

C-33. 1960, ETSUZAN-MARU (Japan)

Date	Statistical area	Catch/3000 ft					Maturity				Sockeye (ocean age)				Chum				
		Sockeye	Chum	Pink	Coho	Chinook	Sockeye		Chum		1	2	3	4	2	3	4	5	6
							I	*M*	*I*	*M*									
May 28	W7548	14	6	5	—	—	1	13	1	5	—	9	5	—	—	—	4	2	—
29	W7550	22	12	11	—	—	1	21	1	11	—	20	2	—	—	—	5	7	—
30	W7550	6	3	3	—	—	0	6	0	3	—	5	1	1	—	—	3	–	
31	8050	11	5	3	—	1	1	10	0	5	—	4	7	—	—	—	2	3	—
June 1	8050	5	9	7	—	—	1	4	2	7	—	1	4	—	—	—	6	3	—
3	E7550	8	9	8	—	—	2	6	3	6	—	4	4	—	—	—	8	1	—
4	E7050	16	9	5	—	1	0	16	2	7	—	5	11	1	—	—	6	3	—
6	E6548	10	3	2	—	—	0	10	0	3	—	5	5	—	—	—	2	1	—
7	E6548	2	1	2	—	—	0	2	0	1	—	1	1	—	—	—	1	1	—
8	E6550	13	7	5	—	—	0	13	0	7	—	1	12	—	—	—	2	5	—
9	E6552	19	17	14	—	—	1	18	1	16	—	5	13	1	—	—	7	10	—
10	E6554	10	17	5	—	1	1	9	2	15	1	1	9	—	—	3	7	7	—
11	E7052	3	24	8	—	2	0	3	1	23	—	1	1	1	—	1	12	11	—
12	E7552	8	1	4	—	—	0	8	0	1	—	3	5	—	—	—	1	1	—
15	W7552	24	4	1	—	—	0	24	0	4	—	20	4	—	—	—	2	2	—
17	W7552	62	2	+	—	—	1	61	0	2	1	58	4	—	—	—	2	–	
18	W7052	88	16	1	—	—	2	86	1	15	1	83	3	—	—	1	14	1	—
19	W7554	97	10	3	—	1	7	90	1	9	8	85	4	—	—	1	9	—	—
21	W7556	56	2	2	—	—	11	45	1	1	12	34	10	—	—	—	1	1	—
22	8054	21	11	7	—	4	2	19	1	10	1	15	5	—	—	—	9	2	—
24	E7554	9	7	1	—	+	0	9	2	5	2	4	3	—	—	—	4	3	—
25	E7556	5	4	8	—	—	0	5	1	3	—	3	2	—	—	—	3	1	—
27	E7056	10	9	15	—	1	3	7	7	2	3	1	6	—	—	1	6	2	—
28	E6556	4	9	13	—	3	1	3	1	8	1	1	3	—	—	—	5	4	—
29	E6554	5	5	9	—	—	1	4	4	1	—	2	3	—	—	—	4	1	—
July 20	E4546	—	13	21	+	—			2	11	—	—	—	—	—	2	4	7	—
21	E5046	—	13	37	1	—			2	11	—	—	—	—	1	1	9	2	—
22	E5048	12	11	39	3	—	0	12	2	9	—	6	6	—	1	1	5	4	—
26	E6054	100	40	1	2	+	98	2	37	3	69	30	2	—	26	4	9	1	—
27	E6056	25	74	+	1	—	21	4	64	10	6	15	4	—	33	9	25	7	—
28	E6558	48	68	+	+	—	47	1	55	13	32	14	2	—	39	7	14	8	—
29	E7058	22	61	+	—	1	22	0	55	6	6	15	1	—	30	4	24	4	—
30	E7058	24	132	—	—	—	23	1	127	5	4	19	1	—	55	23	50	4	—
31	E7056	17	88	—	1	1	16	1	88	0	4	12	1	—	55	12	18	4	—
Aug. 1	E7056	21	43	—	—	1	21	0	41	2	5	16	1	—	12	6	20	5	—
3	E6556	2	12	+	—	—	2	0	11	1	1	1	—	—	3	1	7	1	—
4	E7056	33	19	—	—	+	32	1	18	1	27	6	1	—	9	1	7	2	—
5	E7056	12	36	+	—	—	12	0	35	1	3	9	—	—	25	1	9	1	—
6	E7054	10	26	—	+	+	9	1	25	1	2	8	1	—	4	10	11	1	
8	E7054	11	9	—	—	—	10	1	5	4	1	10	1	—	—	2	6	1	—
9	E6552	21	8	+	1	—	19	2	8	0	3	18	—	—	1	1	4	3	—
10	E6552	33	13	1	5	+	27	6	11	2	10	20	3	—	2	3	7	1	—
11	E6052	13	13	—	7	—	1	12	10	3	4	6	3	—	—	6	6	1	—
14	E6552	29	13	—	6	+	28	1	12	1	3	26	1	—	1	3	8	1	—
15	E6552	6	11	—	4	1	6	0	9	2	1	5	—	—	—	1	9	1	—
16	E6552	19	16	1	3	1	18	1	15	1	5	13	1	—	—	3	11	2	—
17	E7050	4	8	—	4	—	3	1	7	1	—	4	—	—	1	2	4	1	—
18	E6550	4	2	—	3	1	3	1	1	1	—	4	—	—	—	1	1	—	—

C-34. 1960, Paragon (U.S.)

Date		Statistical area	Catch/3000 ft					Maturity				Sockeye (ocean age)				Chum					
			Sockeye	Chum	Pink	Coho	Chinook	Sockeye		Chum[1]		1	2	3	4	2	3	4	5	6	?
								I	*M*	*I*	*M*										
May	18	W7052	2	3	1	—	+	—	2	—	—	—	1	1	—	—	—	1	2	—	—
	19	W7052	1	8	+	—	—	—	1	—	—	—	1	—	—	—	—	4	4	—	—
	22	W7052	2	7	—	—	—	—	2	—	—	—	1	1	—	—	—	4	3	—	—
	23	W7550	34	11	3	—	—	1	33	—	—	—	23	11	—	—	1	4	6	—	—
	24	W7550	11	3	7	—	—	—	11	—	—	—	7	4	—	—	—	1	2	—	—
	27	W7546	2	12	8	—	—	2	—	—	—	—	1	1	—	—	—	11	1	—	—
	28	W7546	6	4	5	—	—	6	—	—	—	—	5	1	—	—	1	2	1	—	—
	29	W7544	22	2	2	+	—	22	—	—	—	2	18	2	—	—	—	1	1	—	—
	31	8046	2	13	6	—	—	2	—	—	—	—	1	1	—	—	1	11	1	—	—
June	1	8046	3	9	3	—	—	3	—	—	—	—	2	1	—	—	—	8	1	—	—
	4	8048	2	10	2	—	—	1	1	—	—	—	1	1	—	—	—	9	1	—	—
	5	E7550	8	12	4	—	—	2	6	—	—	—	4	4	—	—	—	8	3	1	—
	6	E7550	59	22	10	—	—	2	57	—	—	1	46	12	—	—	—	17	4	1	—
	7	8050	26	5	2	—	—	—	26	—	—	—	23	3	—	—	—	4	1	—	—
	15	8052	45	2	8	—	—	—	45	—	—	—	40	5	—	—	—	1	1	—	—
	16	8054	34	4	2	—	1	—	34	—	—	—	28	6	—	—	1	2	1	—	—
	17	8054	3	3	4	—	—	—	3	—	—	—	2	1	—	—	—	1	2	—	—
	18	W7556	9	3	2	—	1	1	9	—	—	—	6	3	—	—	—	2	1	—	—
	19	W7556	14	15	11	—	1	1	13	—	—	1	6	7	—	—	—	7	8	—	—
	20	W7556	46	8	1	—	+	—	46	—	—	—	32	14	—	—	—	6	2	—	—
	21	W7556	52	15	1	—	—	—	52	—	—	—	42	10	—	—	—	9	6	—	—
	22	W7054	70	3	—	—	+	—	70	—	—	—	65	5	—	—	—	3	—	—	—
	23	W7554	24	4	1	—	—	—	24	—	—	—	23	1	—	—	—	3	1	—	—
	24	W7054	27	29	2	—	+	1	26	—	—	1	25	1	—	—	1	26	1	1	—
	25	W7052	28	14	2	—	—	1	27	—	—	—	27	1	—	—	2	11	1	—	—
	26	W7052	16	23	1	—	—	—	16	—	—	—	12	4	—	—	2	20	1	—	—
	27	W7550	13	8	1	—	—	10	3	—	—	2	10	1	—	—	1	6	1	—	—
	28	W7550	27	15	3	—	—	26	1	—	—	1	25	1	—	—	2	12	1	—	—
	29	W7548	6	27	—	—	—	—	—	—	—	—	5	1	—	—	13	13	1	—	—
July	7	W7552	9	7	1	—	1	4	5	—	—	—	8	1	—	—	1	5	1	—	—
	8	W7552	4	5	—	—	+	2	2	—	—	—	3	1	—	—	3	2	—	—	—
	9	W7552	1	2	—	—	—	1	—	—	—	—	1	—	—	—	1	1	—	—	—
	11	W7550	35	5	+	1	1	27	8	—	—	2	26	7	—	—	3	1	1	—	—
	12	W7550	26	5	1	+	—	17	9	—	—	4	17	5	—	—	4	1	—	—	—
	13	W7550	15	14	1	2	—	13	2	—	—	1	13	1	—	1	9	3	1	—	—
	15	W7550	8	18	2	3	+	7	1	—	—	1	6	1	—	2	14	2	—	—	—
	17	W7050	20	14	3	2	1	18	2	—	—	8	11	1	—	1	9	3	1	—	—
	18	W7550	63	32	4	4	+	51	12	—	—	23	34	6	—	1	22	8	1	—	—
	19	W7550	32	9	4	2	—	29	3	—	—	15	16	1	—	—	6	3	—	—	—
	20	W7550	31	19	2	2	—	24	10	—	—	9	16	6	—	1	16	2	—	—	—
	21	W7050	97	121	13	1	—	89	8	—	—	70	23	4	—	—	103	18	—	—	—
	23	W7052	19	122	8	1	—	17	2	—	—	13	5	1	—	1	109	11	1	—	—
	25	W7052	8	140	11	2	—	5	3	—	—	2	3	3	—	3	121	16	—	—	—

[1] Maturity data for chum salmon are lacking.

C-35. 1960, Pioneer (U.S.)

Date	Statistical area	Catch/3000 ft					Maturity				Sockeye (ocean age)				Chum					
		Sockeye	Chum	Pink	Coho	Chinook	Sockeye		Chum[1]		1	2	3	4	2	3	4	5	6	?
							I	*M*	*I*	*M*										
May 28	E 7050	14	5	1	—	—	—	14	—	—	—	3	10	1	—	1	3	1	-	
29	E 7050	3	2	4	—	—	—	3	—	—	—	2	1	-	—	-	1	1		
30	E 7052	9	12	4	—	—	—	9	—	—	—	2	7	-		—	7	5	--	
31	E 7052	12	3	1	—	—	2	10	—	—	1	2	8	1	—	—	1	2	—	
June 5	E 7054	3	10	3	—	1	—	3	—	—	—	1	2	—	—	—	4	6		
6	E 7052	3	4	1	—	+	—	3	—	—	—	1	2	—		—	2	2	—	
7	E 7052	2	2	1	—	—	—	2	—	—	—	1	1	-	-		1	1		—
8	E 7552	7	12	8	—	—	1	6	—	—	—	3	4	—	—	1	8	3	—	
9	E 7552	2	4	3	—	+	—	2	—	—	—	1	1	—	—	1	2	1		
10	8052	3	2	1	—	—	—	3	—	—	—	2	1	—	—		1	1	- -	
11	8052	6	3	—	—	—	—	6	—	—	—	5	1			—	2	1	-	
18	8052	23	2	2	—	—	—	23	—	—	—	21	2		-		1	1	—	
19	8054	36	3	—	—	—	2	34	—	—	2	31	3	—	-		2	1	—	-
20	8054	25	6	+	—	—	—	25	—	—	—	21	4	—	-	1	4	1	—	
21	8054	5	13	9	—	+	1	4	—	—	1	3	1	—	—	1	10	2	—	
23	E 7554	12	2	1	—	—	—	12	—	—	—	5	7	—	-	-	2		—	-
25	E 7054	3	4	6	—	+	—	3	—	—	1	1	1	-		—	3	1		-
27	E 7552	2	25	2	—	—	—	2	—	—	—	1	1	—		1	23	1		
29	E 7050	18	13	1	—	—	14	4	—	—	4	10	3	1		5	8	--		
30	E 7550	29	3	1	1	—	26	3	—	—	17	11	1			1	1	1		
July 2	8048	5	7	—	+	+	5	—	—	—	4	1	—	—	4	2	1			-
3	8050	13	8	+	2	—	12	1	—	—	4	8	1		1	2	4	1		
4	8050	17	14	+	+	1	14	3	—	—	1	14	2	-		9	5	—	—	—
14	E 7052	6	19	—	—	+	6	—	—	—	2	3	1	—	13	3	2	1		
16	E 7052	43	25	+	+	—	41	2	—	—	10	29	4	-	12	6	6	1	-	
17	E 7052	17	19	+	—	—	16	1	—	—	4	12	1		13	1	4	1	—	—
18	E 7050	27	53	+	1	—	26	2	—	—	11	15	1	—	46	2	3	2	—	—
19	E 7050	10	7	—	2	—	9	1	—	—	1	8	1	-	5	—	1	1	—	—
27	E 7550	17	15	3	2	—	13	4	—	—	—	15	2	-	6	8	1	-	—	—
28	E 7550	60	4	1	1	—	53	7	—	—	18	41	1			3	1	—	-	
29	E 7550	35	4	—	12	1	32	3	—	—	3	30	2			3	1			
Aug. 1	E 7550	36	7	—	14	—	35	1	—	—	13	22	1	—	1	5	1			
14	8050	75	12	1	2	—	69	6	—	—	32	39	4	—	1	10	1			
17	8050	45	14	—	2	—	44	1	—	—	15	29	1		1	12	1			
18	8050	45	12	—	3	—	43	2	—	—	13	31	2		1	9	2			
20	8050	32	5	—	1	—	31	1	—	—	3	28	1		1	3	1			
24	W6052	1	6	—	+	—	11	—	—	—	—	1				5	1	-		
25	W6052	1	5	1	+	—	1	—	—	—	—	1				4	1			
26	W6054	2	4	+	+	—	—	—	—	—	—	1	1		1	1	2			

[1] Maturity data for chum salmon are lacking.

APPENDIX TABLE D. REPORTED SALMON CATCH AND EFFORT STATISTICS FOR THE JAPANESE MOTHERSHIP FISHERY, BY 10-DAY PERIOD AND STATISTICAL AREA, 1952–1960

(All data were provided by the Fisheries Agency of Japan. Data for 1952 are in actual numbers; those for subsequent years are in thousands. For each species, the " plus " sign indicates a catch of less than 500 fish.)

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D-1. 1952.

10-day period	Statistical area	No. of tans[1]	Catch (no. of fish) Sockeye	Chum	Pink	Coho	Chinook	Total
Early May	E6048	110	44	78	—	—		122
	E6548	390	245	41	—	—	1	287
	E7050	221	180	112	—	—	—	292
Mid-May	E7052	835	666	1,153	—	—	—	1,819
	E7050	781	470	106	—	—	—	576
	E7550	25,790	42,291	41,910	1	—	6	84,208
Late May	E7550	48,687	121,209	80,585	507	—	15	202,316
Early June	E7550	65,381	172,775	84,940	6,309	—	51	264,075
Mid-June	E7052	20,401	24,039	30,279	4,841	—	26	59,185
	E7050	21,005	23,857	35,583	4,474	1	9	63,924
	E7550	20,149	29,902	25,157	2,780	3	4	57,846
Late June	E7050	68,215	78,491	135,348	31,124	173	70	245,206
Early July	E6550	53,123	101,402	41,481	59,263	375	337	202,858
	E7050	19,431	34,497	22,715	13,916	167	27	71,322
Mid-July	E6050	68,848	87,119	85,156	240,000	4,890	571	417,736
	E6550	3,510	5,303	2,189	8,780	44	5	16,321
Late July	E6050	47,591	14,723	39,744	276,471	15,192	225	346,355
	E6048	986	19	447	3,205	304	1	3,976
Early August	E6050	5,459	1,265	2,267	46,338	3,045	8	52,923
Total		470,913	738,497	629,291	698,009	24,194	1,356	2,091,347

[1] Actual number of tans; length of one tan of gillnet was 158 feet.

D-2. 1953.

10-day period	Statistical area	1,000's of tans[1]	Catch (in 1,000's of fish) Sockeye	Chum	Pink	Coho	Chinook	Total
Early May	E7550	5	8	10	+	+	+	18
	E7548	5	6	4	+	+	+	10
Mid-May	E7550	64	42	44	+	+	+	86
	E7548	98	77	73	+	+	+	150
Late May	E7050	3	2	3	+	−	+	5
	E7048	67	80	61	+	+	+	141
	E7548	45	53	66	+	+	+	119
Early June	E7050	16	12	40	+	+	+	52
	E7048	106	124	335	6	+	+	465
	E7548	4	2	3	+	−	+	5
Mid-June	E7050	107	67	413	65	+	+	545
	E7048	49	33	198	10	+	+	241
Late June	E6050	19	41	58	11	+	+	110
	E6550	64	128	198	44	+	+	370
	E7050	43	38	132	31	+	+	201
Early July	E6050	25	49	68	35	+	+	152
	E6552	6	10	31	22	+	+	63
	E6550	144	290	442	350	3	+	1,085
Mid-July	E5550	5	12	10	24	3	+	49
	E6052	49	83	70	198	11	+	362
	E6050	102	152	130	294	29	1	606
	E6552	13	14	24	32	+	+	70
	E6550	5	4	9	22	+	+	35
Late July	E5550	12	15	12	63	14	+	104
	E6052	17	15	23	158	14	+	210
	E6050	151	179	163	1,065	138	2	1,547
Early August	E5550	14	6	12	84	13	+	115
	E6050	88	20	58	443	88	+	609
Mid-August	E6052	10	5	14	88	15	+	122
	E6050	9	+	8	18	9	+	35
Total		1,345	1,567	2,712	3,063	337	3	7,682

[1] Length of one tan of gillnet was 170 feet.

D-3. 1954.

10-day period	Statistical area	1,000's of tans[1]	Catch (in 1,000's of fish) Sockeye	Chum	Pink	Coho	Chinook	Total
Mid-May	E7050	11	7	24	+	+	+	31
	E7048	40	107	156	+	+	+	263
	E7550	25	56	89	1	+	+	146
	E7548	32	66	121	+	+	+	187
Late May	E7050	3	5	14	+	−	+	19
	E7048	145	169	444	4	+	+	617
	E7550	4	5	13	+	−	+	18
	E7548	22	30	41	+	+	+	71
Early June	E6548	102	140	326	15	−	+	481
	E7050	13	10	41	1	−	+	52
	E7048	154	145	579	16	+	+	740
Mid-June	E6050	27	35	108	7	−	+	150
	E6048	11	12	23	3	−	+	38
	E6552	5	3	17	2	−	+	22
	E6550	75	72	203	26	+	1	302
	E6548	57	74	163	19	+	+	256
	E7052	16	14	90	3	−	+	107
	E7050	158	143	737	28	+	1	909
	E7048	9	6	31	1	−	+	38
Late June	E6052	27	12	123	7	+	+	142
	E6050	105	85	325	23	+	1	434
	E6048	9	12	34	2	−	+	48
	E6552	6	4	19	2	−	+	25
	E6550	156	184	539	36	+	2	761
	E7052	15	14	94	3	+	+	111
	E7050	67	63	330	15	+	1	409
Early July	E5548	40	20	294	103	1	+	418
	E6052	3	1	9	1	+	+	11
	E6050	35	35	154	6	+	+	195
	E6048	84	93	554	172	4	1	824
	E6550	49	126	129	8	+	+	263
	E6548	184	553	549	68	5	8	1,183
Mid-July	E5550	30	24	62	124	6	1	217
	E5548	62	12	137	554	29	1	733
	E6052	22	51	97	7	2	1	158
	E6050	107	242	390	124	11	2	769
	E6048	189	86	499	947	69	5	1,606
Late July	E5550	41	44	49	190	35	1	319
	E5548	144	62	149	1,119	144	1	1,475
	E6052	118	288	372	33	32	6	731
	E6050	136	272	391	295	105	8	1,071
Early August	E5550	94	71	101	212	72	1	457
	E5548	151	28	85	507	174	1	795
	E6050	150	111	226	433	153	4	927
	E6048	40	7	45	160	75	1	288
Mid-August	E5550	72	83	77	70	74	5	309
	E5548	102	55	97	197	156	3	508
	E6050	71	39	101	131	100	7	378
	E6048	64	5	51	102	116	8	282
Late August	E5550	25	25	51	17	27	3	123
	E6048	1	+	3	2	3	+	8
Total		3,308	3,806	9,356	5,796	1,393	74	20,425

[1] Length of one tan of gillnet was 180 feet.

D-4. 1955.

10-day period	Statistical area	1,000's of tans[1]	Catch (in 1,000's of fish) Sockeye	Chum	Pink	Coho	Chinook	Total
Early May	E6548	39	65	149	–	–	+	214
	E7050	5	8	21	–	–	+	29
	E7048	35	92	130	+	–	+	222
Mid-May	E6550	25	30	100	+	–	+	130
	E6548	71	70	149	+	–	+	219
	E7050	26	30	117	–	–	+	147
	E7048	378	837	1,037	18	–	+	1,892
	E7548	16	30	45	–	–	+	75
Late May	E6548	329	610	812	43	–	1	1,466
	E7048	299	595	854	12	+	1	1,462
	E7548	27	49	71	1	–	+	121
Early June	E5050	53	2	338	6	1	+	347
	E6052	+	+	+	+	–	+	
	E6048	67	86	165	311	+	+	562
	E6550	6	9	28	3	–	+	40
	E6548	536	942	1,237	733	1	2	2,915
	E7048	113	223	401	83	–	1	708
	E7548	3	5	8	1	–	+	14
Mid-June	E5050	111	15	660	205	–	+	880
	E6050	33	41	230	10	–	+	281
	E6048	154	162	414	42	+	[illegible]	618
	E6550	87	113	470	68	–	+	651
	E6548	344	993	1,402	1,273	1	1	3,670
	E7052	4	3	22	7	+	+	32
	E7050	41	59	308	62	–	+	429
	E7048	4	7	19	7	–	+	33
	E7548	+	+	+	+	–	+	
Late June	E5050	104	15	477	1,095	+	1	1,588
	E5048	6	1	10	45	+	+	56
	E6048	50	84	128	251	+	+	463
	E6552	7	8	15	3	+	+	26
	E6550	129	265	506	226	+	1	998
	E6548	437	687	1,433	1,154	2	1	3,277
	E7050	62	134	330	177	+	+	[illegible]
	E7048	42	120	112	110	+	+	342
Early July	E5052	66	18	444	985	+	+	1,447
	E5050	14	3	80	243	+	+	326
	E6052	37	63	36	35	+	+	134
	E6050	182	438	372	671	11	1	1,493
	E6048	11	19	36	33	+	+	88
	E6556	+	+	+	+	+	+	
	E6552	24	48	40	23	+	+	111
	E6550	224	599	399	254	3	1	1,256
	E6548	44	91	54	75	+	+	220
	E7050	30	60	56	75	+	+	191
Mid-July	E5054	34	8	178	1,083	+	+	1,269
	E5052	51	17	336	1,106	+	+	1,459
	E5550	129	121	249	980	33	+	1,383

Continued . .

D-4. 1955 (Continued).

10-day period	Statistical area	1,000's of tans[1]	Catch (in 1,000's of fish) Sockeye	Chum	Pink	Coho	Chinook	Total
Mid-July (cont.)	E5548	78	58	103	757	56	1	975
	E6056	+	+	+	+	+	+	
	E6052	104	130	113	131	+	+	374
	E6050	205	241	302	902	25	1	1,471
	E6048	106	41	101	861	36	1	1,040
	E6552	8	15	14	4	+	+	33
	E6550	95	183	188	83	5	1	460
	E6548	5	5	5	2	1	+	13
Late July	E5054	11	2	17	102	1	+	122
	E5052	62	60	192	1,656	35	+	1,943
	E5050	22	16	63	508	7	+	594
	E5554	+	+	+	+	+	+	
	E5550	243	209	358	994	121	3	1,685
	E5548	166	64	172	1,161	179	3	1,579
	E6052	71	133	233	66	9	+	441
	E6050	94	90	165	252	15	+	522
	E6048	62	12	40	418	19	+	489
Early August	E5052	61	75	103	1,214	87	1	1,480
	E5050	27	38	38	231	71	+	378
	E5550	244	307	383	410	289	4	1,393
	E5548	249	88	154	702	459	6	1,409
	E6052	38	62	65	6	26	+	159
	E6050	79	61	62	62	178	2	365
	E6048	177	31	151	516	555	5	1,258
Mid-August	E5052	49	18	19	102	99	+	238
	E5050	25	12	6	33	56	+	107
	E5550	57	65	78	24	41	+	208
	E5548	32	5	20	29	38	1	93
	E6052	111	119	147	1	71	5	343
	E6050	328	310	373	50	344	6	1,083
	E6048	79	7	64	61	110	3	245
	E6552	46	63	32	+	10	4	109
Late August	E5550	31	30	20	3	8	1	62
	E6052	69	82	69	+	17	+	168
	E6050	89	101	40	5	19	2	167
	E6552	70	91	133	1	13	3	241
	E6550	4	4	9	+	+	+	13
Total		7,717	10,703	18,510	22,856	3,052	64	55,185

[1] Length of one tan of gillnet was 180 feet.

D-5. 1956.

10-day period	Statistical area	1,000's of tans[1]	Catch (in 1,000's of fish) Sockeye	Chum	Pink	Coho	Chinook	Total
Early May	E6548	7	13	21	–		–	34
	E6546	189	190	407	+		+	597
	E7050	54	70	197	–		–	267
	E7048	80	68	180	–		+	248
	E7046	11	11	17	–		+	28
	E7550	7	2	7	–		–	9
	E7548	20	17	65	–	–	+	82
Mid-May	E6548	29	39	75	–	–	+	114
	E6546	14	9	21	–		+	30
	E7050	320	328	849	+		+	1,177
	E7048	267	229	724	+			953
	E7046	7	6	14	–		–	20
	E7550	11	13	33	–		–	46
	E7548	11	10	54	–		+	64
Late May	E6546	141	193	299	26	–	–	518
	E7050	59	40	142	1		+	183
	E7048	161	108	473	1		+	582
	E7550	202	262	435	9		+	706
	E7548	231	217	471	13		+	701
Early June	E6546	151	150	204	113	–	+	467
	E7052	155	178	394	13		+	585
	E7050	289	347	741	26		+	1,114
	E7048	115	52	240	8		+	300
	E7046	30	21	83	4		+	108
	E7550	87	88	207	23	–	+	318
Mid-June	E7052	310	189	831	38		2	1,060
	E7050	665	603	1,661	104		2	2,370
	E7048	13	15	17	2	–	–	33
	E7554	49	38	216	6		2	262
	E7552	115	139	357	12		2	510
	E7550	11	12	20	1		–	33
Late June	E5052	23	7	219	145		–	371
	E5050	88	20	818	425		–	1,263
	E7056	11	2	28	+			30
	E7054	21	5	52	1		–	58
	E7052	49	78	51	4	–	–	133
	E7050	103	89	128	5	–	–	222
	E7048	13	18	7	1		–	26
	E7554	99	54	152	1		1	208
	E7552	340	509	357	6	–	3	875
	E7550	252	397	168	9	1	1	576
	8054	160	219	156	2		9	386
	8052	193	195	110	3	–	16	324
	8050	48	82	13	1	2	–	98
Early July	E5052	74	35	796	302	–	–	1,133
	E5050	49	35	376	260	1		672
	E6546	36	1	5	34	71	1	112
	E7058	58	16	223	1			240
	E7056	56	10	203	1			214

Continued

D-5. 1956 (Continued).

10-day period	Statistical area	1,000's of tans[1]	Catch (in 1,000's of fish)					
			Sockeye	Chum	Pink	Coho	Chinook	Total
Early July (cont.)	E7052	92	135	35	3	1	+	174
	E7050	308	348	81	12	8	1	450
	E7048	96	57	13	25	130	2	227
	E7046	283	2	21	80	688	10	801
	E7552	1	1	1	-	-	+	2
	E7550	88	157	28	4	21	+	210
	E7548	73	6	8	4	89	1	108
	E7546	12	-	1	1	39	+	41
	8058	20	4	179	-		1	184
	8056	47	16	101	-		1	118
	8054	29	25	54	-	-	5	84
	8052	56	41	53	2	-	4	100
	8050	108	153	32	4	11	+	200
	8048	12	10	1	-	2	+	13
Mid-July	E5052	45	116	369	255	6	+	746
	E5050	79	138	360	1,548	33	+	2,079
	E5550	27	56	58	402	9	+	525
	E5548	20	24	8	620	25	+	677
	E6052	23	60	52	23	5	+	140
	E6050	54	74	80	582	26	+	762
	E6048	83	12	42	1,617	126	1	1,798
	E6550	13	10	15	12	38	1	76
	E6548	14	1	11	27	38	2	79
	E6546	353	1	105	665	356	7	1,134
	E7058	91	90	487	2	-	1	580
	E7048	185	4	41	12	309	4	370
	E7046	113	-	12	21	170	4	207
	8058	70	20	502	1	-	+	523
Late July	E5052	56	224	208	866	36	+	1,334
	E5050	21	18	35	898	29	+	980
	E5550	80	202	270	536	30	1	1,039
	E5548	158	82	138	2,692	128	3	3,043
	E6052	141	531	309	66	75	2	983
	E6050	213	304	312	1,009	239	5	1,869
	E6048	204	17	108	1,627	418	13	2,183
	E6558	47	192	515	1	-	+	708
	E6556	27	79	105	-	-	+	184
Early August	E5052	35	64	44	668	13		789
	E5550	66	149	111	36	21		317
	E5548	219	29	190	923	137	5	1,284
	E6052	177	359	238	59	132	2	790
	E6050	50	41	55	35	68	2	201
	E6048	179	109	121	256	190	6	682
	E6552	166	478	438	9	61	2	988
	E6550	15	5	13	2	29	-	49
	E6548	13	-	9	6	39	1	55
	E7052	6	20	21	1	7	-	49
Mid-August	E5548	12	-	7	24	6		37
	E6052	7	3	5	-	3	+	11
	E6050	7	2	3	2	3	+	10
	E6552	3	3	1	-	1	+	5
Total		9,781	9,901	19,323	17,239	3,870	126	50,459

[1] Length of one tan of gillnet was 180 feet.

D-6. 1957.

10-day period	Statistical area	1,000's of tans[1]	Catch (in 1,000's of fish) Sockeye	Chum	Pink	Coho	Chinook	Total
Early May	E6048	24	70	39	1	–	+	110
	E6550	62	209	159	2	–	+	370
	E6548	59	191	70	1	–	+	262
	E6546	65	129	32	1	–	–	162
	E7050	18	72	72	+	–	+	144
	E7048	4	17	4	+	–	+	21
Mid-May	E5548	0.5	2	2	+	–	+	4
	E6050	24	31	61	1	–	+	93
	E6048	89	248	134	2	–	+	384
	E6552	115	295	335	1	–	+	631
	E6550	201	592	469	8	–	1	1,070
	E6548	91	301	123	8	–	+	432
	E6546	7	23	5	+	–	–	28
	E7052	118	364	258	1	–	+	623
	E7050	246	793	459	37	–	1	1,290
	E7048	55	139	63	11	–	+	213
Late May	E6050	7	6	6	+	–	+	12
	E6048	71	246	262	22	–	+	530
	E6552	8	22	11	+	–	+	33
	E6550	228	596	487	36	–	+	1,119
	E6548	155	508	312	58	–	+	878
	E6546	89	368	115	38	+	+	521
	E7050	217	486	300	63	–	+	849
	E7048	39	80	35	11	–	–	126
	E7550	41	100	41	30	–	+	171
Early June	E5050	42	2	482	158	–	+	642
	E5548	29	12	144	41	–	+	197
	E6052	1	1	4	+	–	+	5
	E6050	66	156	187	35	+	+	378
	E6048	205	579	539	496	+	+	1,614
	E6552	30	48	43	5	–	+	96
	E6550	155	307	293	181	+	+	781
	E6548	91	303	109	139	+	+	551
	E6546	72	226	81	190	1	+	498
	E7052	78	318	242	124	–	+	684
	E7050	187	586	345	422	+	1	1,354
	E7550	28	102	36	106	–	+	244
Mid-June	E5052	18	1	116	85	–	+	202
	E5050	83	5	526	462	–	+	993
	E6052	9	21	26	32	–	+	79
	E6050	60	242	108	220	+	+	570
	E6048	28	118	49	157	+	+	324
	E6552	24	101	74	39	+	+	214
	E6550	44	157	118	312	+	+	587
	E6548	43	171	103	283	+	+	557
	E7054	10	27	13	5	–	+	45
	E7052	96	337	245	111	–	1	694
	E7050	74	286	207	569	+	+	1,062
	E7554	63	331	82	180	–	1	594
	E7552	176	1,561	174	428	–	2	2,165

Continued . . .

D-6. 1957 (Continued).

10-day period	Statistical area	1,000's of tans[1]	Catch (in 1,000's of fish) Sockeye	Chum	Pink	Coho	Chinook	Total
Mid-June (cont.)	E7550	19	95	18	154	+	+	267
	8056	56	334	32	103	—	1	470
	8054	95	611	54	221	—	+	886
	8052	56	513	26	44	—	+	583
Late June	E5052	29	2	77	260	+	+	339
	E5050	93	22	364	1,197	+	+	1,583
	E6052	213	621	313	571	2	+	1,507
	E6050	62	153	27	465	2	+	647
	E6552	170	495	181	805	2	+	1,483
	E6550	30	69	36	318	1	1	425
	E7052	17	43	14	96	+	+	153
	E7050	18	45	12	77	+	+	134
	E7558	54	155	48	184	—	2	389
	E7556	9	12	3	67	+	—	82
	E7552	17	30	10	80	+	—	120
	8058	102	277	56	220	+	3	556
	8056	96	390	47	197	+	3	637
	8054	123	369	51	532	+	2	954
	8052	36	122	24	111	+	—	257
Early July	E5052	21	10	120	479	1	+	610
	E5050	78	32	389	1,285	5	+	1,711
	E5550	57	134	63	899	5	+	1,101
	E5548	38	32	38	418	15	+	503
	E6052	212	553	199	896	9	1	1,658
	E6050	285	566	164	2,506	20	1	3,257
	E6048	20	15	20	313	14	+	362
	E6552	151	487	77	873	11	1	1,449
	E6550	14	27	6	86	+	+	119
	E6548	4	8	2	18	+	+	28
	E7056	1	+	+	11	+	+	11
	E7054	33	35	8	262	+	+	305
	E7558	18	23	6	116	—	+	145
	E7556	9	13	2	104	—	+	119
	8058	27	20	52	73	—	+	145
	8056	45	28	64	267	—	+	359
Mid-July	E5052	49	69	252	772	20	+	1,113
	E5050	60	44	220	939	33	+	1,236
	E5550	87	130	61	796	15	1	1,003
	E5548	170	86	57	1,300	97	1	1,541
	E6052	228	806	171	555	21	2	1,555
	E6050	192	323	108	1,343	39	1	1,814
	E6048	73	22	17	839	41	+	919
	E6558	16	27	16	146	+	+	189
	E6556	24	45	7	211	+	+	263
	E6552	34	87	7	80	2	+	176
	E6550	14	41	13	16	13	+	83
	E7058	15	16	10	61	—	+	87
	E7056	8	5	3	53	—	+	61
	E7556	9	5	9	13	—	+	27
Late July	E5052	23	23	42	442	8	+	515
	E5050	43	65	73	755	35	+	928
	E5550	18	28	16	57	6	+	107
	E6050	35	53	34	83	23	+	193
Total		7,151.5	20,102	11,919	27,881	441	27	60,370

[1] Length of one tan of gillnet was 180 feet.

D-7. 1958.

10-day period	Statistical area	1,000's of tans[1]	Catch (in 1,000's of fish) Sockeye	Chum	Pink	Coho	Chinook	Total
Mid-May	E6550	84	172	138	1	–	+	311
	E6548	140	309	346	+	+	+	655
	E6546	111	151	144	1	–	+	296
	E7050	87	93	146	1	–	+	240
	E7048	161	232	232	4	–	+	468
	E7046	46	51	65	2	–	+	118
	E7548	8	8	11	1	–	+	20
Late May	E6048	107	89	361	2	–	+	452
	E6552	16	30	39	5	–	+	74
	E6550	131	207	184	4	–	+	395
	E6548	367	709	764	10	–	+	1,483
	E6546	157	288	372	17	+	+	677
	E7052	24	23	57	6	–	+	86
	E7050	84	88	190	12	–	+	290
	E7048	30	39	37	2	–	+	78
	E7046	18	41	31	1	–	+	73
	E7548	8	9	7	+	–	+	16
Early June	E5052	46	2	296	15	–	+	313
	E6054	38	53	51	15	–	+	119
	E6052	15	9	23	1	–	+	33
	E6552	69	66	72	7	–	+	145
	E6550	244	421	544	62	+	1	1,028
	E6548	189	399	486	100	+	1	986
	E6546	73	107	136	141	+	+	384
	E7052	104	95	237	38	+	+	370
	E7050	247	266	423	63	–	1	753
	E7048	36	69	62	8	–	+	139
Mid-June	E5052	60	5	349	434	+	+	788
	E5550	65	30	215	334	+	1	580
	E5548	22	6	54	136	–	+	196
	E6054	46	80	42	57	–	1	180
	E6052	15	8	34	58	+	+	100
	E6050	100	82	227	269	+	1	579
	E6048	198	235	566	902	+	1	1,704
	E6550	179	309	390	104	+	1	804
	E6548	209	417	395	187	+	+	999
	E6546	40	65	108	75	+	+	248
	E7052	76	98	314	47	+	1	460
	E7050	54	64	97	18	+	+	179
	E7048	30	67	54	6	–	+	127
Late June	E5052	56	5	308	601	–	+	914
	E5550	30	18	60	130	+	+	208
	E6052	69	74	112	104	+	1	291
	E6050	112	192	113	171	+	+	476
	E6048	105	131	114	270	+	+	515
	E6552	71	136	136	43	+	1	316
	E6550	230	506	371	105	1	1	984
	E6548	286	853	415	173	2	1	1,444
	E6546	58	129	86	47	1	1	264
	E7052	34	46	85	5	+	+	136
	E7050	20	32	29	2	–	+	63

Continued

D–7. 1958 (Continued).

10-day period	Statistical area	1,000's of tans[1]	Catch (in 1,000's of fish) Sockeye	Chum	Pink	Coho	Chinook	Total
Early July	E5052	56	6	231	223	–	–	460
	E5550	117	56	293	269	1	–	619
	E5548	260	91	850	1,252	12	1	2,206
	E6054	9	13	13	6	+	+	32
	E6052	62	126	152	67	+	1	346
	E6050	187	452	410	205	3	1	1,071
	E6048	218	91	499	1,182	18	1	1,791
	E6552	24	115	53	2	+	+	170
	E6550	26	78	54	11	1	+	144
	E6548	43	82	111	20	4	+	217
Mid-July	E5052	61	11	214	439	6	+	670
	E5550	122	200	290	254	7	1	752
	E5548	329	130	463	1,981	38	1	2,613
	E6050	261	553	645	248	45	2	1,493
	E6048	279	109	342	1,560	126	1	2,138
	E6548	58	98	64	52	163	+	377
	E6546	43	11	53	221	32	+	317
Late July	E5052	59	16	140	396	18	+	570
	E5550	152	445	314	135	47	1	942
	E5548	198	90	313	690	66	2	1,161
	E6050	242	478	388	133	207	1	1,207
	E6048	201	53	313	463	351	3	1,183
	E6550	43	109	66	7	55	+	237
	E6548	90	31	55	34	255	1	376
	E6546	43	3	32	34	229	1	299
Early August	E5052	55	9	84	240	27	+	360
	E5550	83	194	254	34	57	1	540
	E5548	9	1	14	58	2	+	75
	E6050	257	414	796	72	307	3	1,592
	E6048	92	4	183	78	190	1	456
	E6550	126	159	248	59	220	2	688
	E6548	145	28	237	107	391	2	765
	E6546	133	2	204	214	420	4	844
	E7052	33	46	112	1	8	+	167
	E7050	66	105	172	5	81	1	364
Total		8,987	12,023	18,790	15,549	3,391	46	49,799

[1] Length of one tan of gillnet was 180 feet.

D-8. 1959.

10-day period	Statistical area	1,000's of tans[1]	Catch (in 1,000's of fish) Sockeye	Chum	Pink	Coho	Chinook	Total
Late May	E6550	200	446	538	2	–	+	986
	E6548	357	823	1,087	39	+	1	1,950
	E6546	309	498	866	121	+	1	1,486
	E7050	108	154	259	1	+	+	414
	E7048	165	231	479	53	+	+	763
Early June	E6048	105	78	470	177	+	+	725
	E6552	43	83	62	1	–	+	146
	E6550	129	200	200	4	–	+	404
	E6548	109	127	181	28	+	+	336
	E6546	268	226	504	384	+	+	1,114
	E7052	99	98	173	14	+	1	286
	E7050	162	118	402	60	–	1	581
	E7048	146	143	336	87	+	1	567
	E7046	30	33	27	36	+	+	96
	E7550	106	106	227	215	+	+	548
	E7548	19	21	54	23	–	+	98
Mid-June	E6050	8	22	23	27	+	+	72
	E6048	175	166	367	664	+	+	1,197
	E6550	78	108	162	106	+	+	376
	E6548	105	127	234	232	1	+	594
	E6546	225	179	393	776	2	+	1,350
	E7052	31	49	114	148	+	+	311
	E7050	108	93	167	183	+	+	443
	E7048	301	487	430	561	1	1	1,479
	E7550	93	166	109	288	+	+	563
Late June	E6052	23	55	26	46	+	+	127
	E6050	59	73	73	154	+	+	300
	E6048	76	46	122	293	1	+	462
	E6552	93	198	175	218	+	1	592
	E6550	294	372	520	940	2	2	1,836
	E6548	234	282	304	831	17	3	1,437
	E6546	100	74	153	291	8	1	527
	E7054	36	45	48	184	+	1	278
	E7052	87	103	173	378	+	+	654
	E7050	151	104	268	401	1	1	775
	E7048	31	36	28	166	3	+	233
Early July	E6052	113	247	173	295	3	+	718
	E6050	110	148	207	272	2	1	630
	E6048	100	51	191	303	7	1	553
	E6558	7	6	23	71	+	+	100
	E6556	14	14	23	109	+	+	146
	E6552	127	153	196	421	2	1	773
	E6550	113	134	204	402	4	3	747
	E6548	9	32	9	19	+	+	60
	E7058	52	46	67	487	+	1	601
	E7056	143	133	173	1,184	2	2	1,494
	E7054	19	7	13	42	+	+	62
	E7052	88	75	108	353	4	1	541
	E7050	26	14	61	78	+	+	153
	E7558	34	25	26	438	+	+	489
	E7556	18	11	14	177	+	+	202

Continued.

D-8. 1959 (Continued).

10-day period	Statistical area	1,000's of tans[1]	Catch (in 1,000's of fish) Sockeye	Chum	Pink	Coho	Chinook	Total
Mid-July	E6052	65	199	125	60	9	1	394
	E6050	23	34	35	32	3	+	104
	E6048	6	4	19	22	1	+	46
	E6558	112	131	278	784	3	1	1,197
	E6556	29	28	22	311	1	+	362
	E6550	7	39	5	4	2	+	50
	E6548	44	93	38	6	77	2	216
	E6546	62	36	57	1	195	1	290
	E7058	241	317	274	1,217	2	13	1,823
	E7056	224	160	127	1,674	17	3	1,981
	E7054	9	3	3	61	+	+	67
	E7052	9	6	4	45	1	+	56
	E7048	10	2	2	+	39	+	43
	E7046	82	45	36	2	300	+	383
	E7558	82	67	44	623	+	2	736
	E7556	60	27	23	526	2	+	578
Late July	E6050	15	38	28	1	50	1	118
	E6048	33	71	73	16	106	2	268
	E6550	8	36	15	4	12	+	67
	E6548	96	275	140	27	306	4	752
	E6546	8	1	6	+	21	+	28
	E7058	86	137	123	385	2	3	650
	E7048	18	33	39	1	49	1	123
	E7046	54	6	22	+	166	1	195
	E7560	37	47	34	67	+	1	149
	E7558	40	24	42	206	+	2	274
Total		7,096	9,125	12,856	18,858	1,424	63	42,326

[1] Length of one tan of gillnet was 180 feet.

D-9. 1960.

10-day period	Statistical area	1,000's of tans[1]	Catch (in 1,000's of fish)* Sockeye	Chum	Pink	Coho	Chinook	Total
Late May	E6552	9.9	13.6	41.5	3.8	–	0.1	59.0
	E6550	138.9	290.4	295.5	14.4	–	0.4	600.7
	E6548	177.0	360.1	316.6	8.0	–	0.3	685.0
	E6546	150.0	261.1	181.9	15.5	+	0.1	458.6
	E7052	11.0	14.2	28.8	2.4	–	0.1	45.5
	E7050	68.0	104.4	117.2	13.7	–	0.2	235.5
	E7048	42.7	89.7	66.5	1.7	–	0.06	158.0
Early June	E6052	50.3	72.8	60.6	4.0	–	0.1	137.5
	E6050	7.9	6.0	8.6	0.1	–	+	14.7
	E6046	75.6	85.2	276.8	121.6	–	0.3	483.9
	E6552	110.2	144.1	175.3	15.1	–	0.2	334.7
	E6550	144.5	221.2	147.1	14.8	–	0.4	383.5
	E6548	19.1	29.5	26.6	2.9	–	0.05	59.1
	E6546	33.5	55.1	34.4	17.1	0.05	0.05	106.7
	E7052	50.5	64.3	73.6	9.0	–	0.1	147.0
	E7050	261.1	287.0	327.0	27.1	+	0.3	641.4
	E7552	55.7	117.2	138.1	15.7	–	0.5	271.5
	E7550	76.9	199.0	95.7	4.1	–	0.3	299.1
Mid-June	E6052	24.6	30.6	60.5	19.5	–	0.2	110.8
	E6050	84.5	70.5	255.7	114.7	+	0.4	441.3
	E6048	32.8	40.2	140.0	61.7	+	0.2	242.1
	E6552	16.9	17.8	41.3	18.2	–	0.2	77.5
	E6550	48.1	67.7	67.4	18.7	–	0.1	153.9
	E6548	19.5	34.3	30.1	4.1	–	0.1	68.6
	E6546	8.7	17.6	8.3	3.8	+	+	29.7
	E7052	43.8	57.8	73.4	16.7	–	0.1	148.0
	E7554	34.6	45.2	99.5	14.7	–	0.3	159.7
	E7552	87.8	168.0	179.4	19.3	+	1.8	368.5
	E7550	84.5	334.0	61.7	5.1	–	0.4	401.2
	8056	58.5	63.1	237.3	25.2	–	4.7	330.3
	8054	204.4	529.8	393.9	51.4	+	7.5	982.6
	8052	198.6	935.2	240.4	22.4	+	3.7	1,201.7
	8050	38.5	136.6	20.8	1.6	–	0.1	159.1
Late June	E6558	37.3	17.6	75.2	110.0	–	3.2	206.0
	E6556	27.6	11.1	37.2	81.0	–	3.0	132.3
	E6552	24.1	33.3	38.8	11.7	+	0.2	84.0
	E6550	24.4	48.6	46.0	6.6	0.15	0.15	101.5
	E6548	42.2	96.5	62.9	8.7	0.5	0.2	168.8
	E7058	125.7	47.6	219.6	108.8	+	10.8	386.8
	E7560	29.4	9.9	89.1	15.3	–	2.8	117.1
	E7558	40.7	15.1	86.2	32.1	–	6.8	140.2
	E7556	23.6	10.6	21.4	6.7	+	2.6	41.3
	E7550	23.7	44.1	44.0	1.4	+	0.1	89.6
	8060	48.4	31.5	102.3	8.5	–	0.7	143.0
	8058	217.9	232.7	609.9	73.0	+	49.4	965.0
	8056	80.3	82.0	193.2	24.4	–	16.3	315.9
	8054	124.0	308.3	160.2	17.1	–	6.7	492.3
	8052	101.7	265.3	138.4	8.9	+	2.0	414.6
Early July	E6052	92.8	176.2	157.9	43.4	0.7	0.7	378.9
	E6050	158.1	382.3	251.2	31.1	2.3	1.1	668.0

Continued . . .

D-9. 1960 (Continued)

10-day period	Statistical area	1,000's of tans[1]	Catch (in 1,000's of fish) Sockeye	Chum	Pink	Coho	Chinook	Total
Early July (cont.)	E6048	136.2	347.8	430.7	36.1	10.9	2.4	827.9
	E6558	46.7	42.4	126.4	164.1		1.6	334.5
	E6556	28.0	23.7	39.6	166.3	-	1.2	230.8
	E6552	72.5	150.2	125.1	31.8	0.7	0.6	308.4
	E6550	75.3	179.1	163.5	16.6	1.4	0.8	361.4
	E6548	168.2	519.8	407.9	22.5	12.2	1.9	964.3
	8058	85.2	59.8	332.5	19.7	-	10.0	422.0
	8056	62.6	23.3	283.9	12.4	-	5.8	325.4
Mid-July	E6052	24.2	55.9	78.5	2.1	0.9	0.1	137.5
	E6050	74.6	171.5	133.2	4.0	5.8	0.5	315.0
	E6048	154.7	382.1	218.0	13.9	20.6	1.1	635.7
	E6558	7.7	8.4	18.1	12.9		0.2	39.6
	E6552	130.0	342.0	228.1	12.2	9.2	1.3	592.8
	E6550	245.0	595.8	376.6	14.9	23.2	1.8	1,012.3
	E6548	269.1	908.9	227.2	23.8	77.7	1.4	1,239.0
	E6546	22.4	4.3	7.7	2.2	37.1	1.0	52.3
	E7050	8.3	16.1	9.3	0.07	2.3	—	27.8
	E7048	9.9	0.1	2.7	0.2	23.9	0.7	27.6
	E7046	74.7	28.2	29.6	4.5	114.7	5.4	182.4
Late July	E6050	36.7	69.3	23.2	0.8	6.2	0.2	99.7
	E6048	177.5	379.8	196.2	20.3	66.4	1.2	663.9
	E6552	32.5	63.7	27.2	0.8	3.5	0.2	95.4
	E6550	115.4	267.2	51.5	2.6	26.5	0.6	348.4
	E6548	239.9	537.4	69.2	8.5	122.3	1.4	738.8
	E6546	10.6	21.2	7.1	+	5.6	0.3	34.2
	E7050	119.6	259.2	44.6	4.4	44.3	0.7	353.2
	E7048	143.7	194.3	65.2	2.4	155.2	3.2	420.3
	E7046	124.2	92.2	51.0	1.1	164.8	3.6	312.7
Early August	E6050	37.9	95.8	30.9	0.5	6.5	0.3	134.0
	E6048	7.6	0.2	10.9	3.7	4.6	0.4	19.8
	E6552	8.4	26.7	2.0	+	0.17	—	28.9
	E6548	9.1	21.3	4.3	0.1	1.7	0.15	27.6
	E7052	61.2	189.9	36.2	3.0	8.2	0.15	237.5
	E7050	8.1	25.2	4.2	0.1	1.9	+	31.4
Total		6,518.2	12,878.8	10,517.3	1,885.4	962.2	180.3	26,424.0

[1] Length of one tan of gillnet was 180 feet.

* Note that " + " in this year represents less than 50 fish, instead of less than 500 fish as in 1952–1959.

APPENDIX TABLE E. CATCH PER TAN (180 FEET) OF SALMON IN THE LANDBASED REGION, BY STATISTICAL AREA AND 10-DAY PERIOD, 1956–1960

(Values less than 0.01 are represented by the " plus " sign; " – " indicates absence in the catch. Data were obtained from Japanese research and training vessels fishing with 4.5″ mesh gillnets.)

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E-1. 1956.

10-day period	Statistical area	Sockeye	Chum	Pink	Coho	Chinook
Early May	E5044	0.01	16	0.10	–	0.01
	E5544	0.01	4.1	0.07	–	+
	E5542	–	3.2	0.19	–	–
Mid-May	E5042	–	0.89	0.15	–	0.01
Late May	E6046	1.6	4.9	0.73	–	+
	E6044	0.21	2.8	0.81	–	+
Early June	E4542	–	0.14	5.9	–	–
	E6046	2.6	2.9	0.29	–	–
Mid-June	E4542	+	0.17	7.1	–	+
Late June	E4042	+	0.02	5.6	–	–
	E4542	–	0.01	7.9	+	–
Early July	E4042	–	–	1.7	–	-
	E4542	+	0.01	4.6	–	
Mid-July	E4544	–	+	4.1	–	
	E4542	+	+	3.2	+	
	E5044	+	0.02	11.0	0.05	0.01
Late July	E4542	–	–	1.7	–	–
	E5046	0.09	0.13	6.8	0.09	-
	E5546	0.01	0.11	23.0	0.69	0.01

E-2. 1957.

10-day period	Statistical area	Sockeye	Chum	Pink	Coho	Chinook
Early May	E5544	+	0.90	0.08	—	0.01
	E5542	—	0.91	0.02	—	
Mid-May	E5042	0.01	0.54	3.0	—	0.01
	E5542	—	0.08	0.40	—	0.01
	E6044	+	0.92	0.24	—	+
Late May	E4544	—	0.13	9.9	—	
	E4542	—	0.46	4.2	—	
	E5042	+	0.52	3.8	—	+
Early June	E4542	+	0.34	4.9	—	+
	E5044	0.02	2.2	5.4	—	
	E5042	+	0.50	2.7	—	+
	E5544	0.01	0.97	3.1	—	+
Mid-June	E5044	0.04	2.0	4.2	+	+
	E5052	0.01	0.36	6.9	—	
Late June	E5044	0.02	0.98	6.7	+	+
	E5042	0.02	0.38	9.3	—	
Early July	E5046	0.21	2.1	7.2	0.44	0.01
	E5044	0.01	0.98	5.5	0.05	+
	E5546	0.14	1.3	6.6	0.65	0.01
Mid-July	E5046	0.25	0.72	10.0	0.70	0.02
	E5546	0.17	0.98	14.0	0.64	0.01
Late July	E5046	0.07	0.18	4.0	0.15	+
	E5546	0.04	0.16	3.3	0.24	+
Early August	E5546	0.01	0.12	0.58	0.12	+

E-3. 1958.

10-day period	Statistical area	Sockeye	Chum	Pink	Coho	Chinook
Early May	E6544	2.2	1.8	0.09	–	–
Mid-May	E4540	–	0.52	0.97	–	–
	E4538	–	1.6	0.83	–	–
	E5042	+	1.9	1.4	–	+
	E5040	–	0.66	3.8	–	–
	E5542	+	0.64	0.34	–	+
	E6544	1.5	1.0	0.22	–	–
Late May	E4540	–	0.48	8.9	–	+
	E5042	+	3.7	2.4	–	+
	E5040	–	1.3	5.8	–	–
	E5542	–	0.66	0.54	–	–
	E6044	0.52	0.97	1.6	–	+
	E6042	–	0.30	0.24	–	–
	E6544	1.4	1.5	0.11	–	–
Early June	E4542	+	1.2	4.9	–	–
	E4540	–	1.7	5.9	–	–
	E5042	–	0.33	2.8	–	–
	E5542	–	0.39	0.15	–	–
Mid-June	E4040	–	0.83	0.52	–	–
	E4542	+	0.66	1.8	–	+
	E5044	0.01	2.6	3.4	+	–
	E5042	0.01	2.7	1.9	+	+
	E6046	1.5	1.7	2.0	–	–
Late June	E5046	–	7.4	3.2	–	–
	E5044	0.02	3.0	3.1	0.04	+
	E5042	–	4.4	1.5	0.01	–
	E5546	–	1.3	1.6	–	–
	E5544	+	1.8	3.2	0.08	0.01
Early July	E4542	–	0.06	2.4	0.05	0.01
	E5042	–	0.07	0.63	0.03	–
	E5546	0.02	1.3	8.4	0.03	+
	E5544	0.01	1.7	9.1	0.21	0.01
	E6046	–	1.8	8.8	0.17	0.01
Mid-July	E5046	0.01	1.1	6.3	0.15	
	E5044	0.01	0.10	8.5	0.13	
	E5546	0.02	0.78	5.4	0.22	+
	E5544	–	1.2	4.5	0.55	+
	E6046	–	0.64	3.6	0.26	0.03
	E6044	–	1.1	1.1	0.47	0.02
Late July	E5046	–	0.05	3.0	0.02	
	E5546	–	0.29	1.5	0.32	0.02
	E5544	–	0.62	1.5	0.93	0.06
	E6046	+	0.83	1.9	0.55	
Early August	E5044	0.15	1.2	0.07	–	–
	E5546	+	0.14	1.6	0.21	0.02
	E5544	–	0.43	0.44	0.05	0.01
	E6046	–	1.2	0.28	0.75	0.01

E-4. 1959.

10-day period	Statistical area	Sockeye	Chum	Pink	Coho	Chinook
Early May	E5542	0.02	1.5	1.0	—	0.01
Mid-May	E5542	—	1.2	3.1	—	—
	E6044	0.24	3.7	2.3	—	—
Late May	E5042	0.01	0.50	4.0	—	0.01
	E5544	0.01	1.0	7.7	—	—
	E5542	+	1.3	8.2	—	0.01
	E6044	0.04	3.7	13.0	—	—
Early June	E5042	—	2.8	3.5	—	0.01
	E5544	—	0.39	2.7	—	—
	E5542	—	1.1	2.8	—	0.01
	E6044	+	1.6	12.0	—	—
Mid-June	E4542	—	0.13	16.0	—	+
	E4540	—	0.13	31.0	—	+
	E5044	0.02	0.85	3.6	—	—
	E5042	0.01	0.51	7.7	+	0.01
Late June	E4544	—	0.20	2.3	0.02	—
	E4542	+	0.26	7.5	+	0.01
	E5044	0.05	1.4	9.5	0.04	+
	E5042	0.01	1.1	11.0	0.02	+
Early July	E5046	0.04	1.8	4.5	0.29	0.01
	E5044	0.03	0.47	3.0	0.09	0.01
	E5546	0.02	0.35	5.9	0.49	0.02
	E5544	0.01	0.41	1.5	0.41	0.03
Mid-July	E5546	0.01	0.25	4.1	0.42	0.01
	E6046	—	0.63	4.5	1.6	0.06
Late July	E5546	—	0.52	1.3	0.51	0.03
	E6046	—	0.50	1.6	0.37	0.03
Early August	E5046	—	0.03	1.1	0.04	0.02
	E5546	+	0.58	0.88	0.12	0.01
Mid-August	E5046	—	0.02	0.90	0.06	0.02
	E5044	—	0.01	0.04	0.02	—
	E5546	—	0.38	0.01	0.01	0.01
	E5544		—	—	—	—
	E6046		0.05	—	—	—

E-5. 1960.

10-day period	Statistical area	Sockeye	Chum	Pink	Coho	Chinook
Early May	E4040	–	0.01	0.30	–	–
	E4540	–	0.60	1.2	–	+
Mid-May	E4540	–	0.81	0.70	–	+
	E5044	0.02	0.46	0.43	–	+
	E5042	–	0.08	0.22	+	0.04
	E5542	–	0.05	0.35	–	0.01
	E6044	0.07	1.0	0.76	–	–
	E6544	0.67	1.1	0.34	–	-
Late May	E4540	–	0.35	1.7	–	–
	E5042	–	0.38	0.40	–	+
	E5040	–	0.14	3.7	–	+
	E5542	–	0.22	0.41	–	0.01
	E6044	0.39	0.20	0.60	+	+
	E6042	+	0.04	0.88	+	+
Early June	E4542	–	0.17	3.1	–	0.01
	E4540	–	0.61	3.9	–	–
	E5042	–	2.2	2.2	+	–
	E5542	0.01	0.77	0.61	+	+
	E6044	0.23	0.16	1.3	+	–
	E6042	–	0.12	0.5	+	–
Mid-June	E4542	+	0.05	1.0	–	+
	E5044	0.01	0.88	2.6	–	+
	E5042	0.01	0.68	1.8	+	0.01
Late June	E5044	0.02	1.6	1.5	0.01	+
	E5042	0.01	1.0	1.2	0.04	0.01
	E5544	0.01	1.2	1.1	0.21	+
	E5542	0.01	0.49	0.41	0.11	0.01
Early July	E5044	0.01	0.59	3.6	0.04	0.01
	E5042	0.01	0.27	1.4	0.04	0.01
	E5544	+	1.6	2.1	0.66	0.05
	E6044	+	0.75	4.9	0.38	0.01
Mid-July	E5044	0.01	0.98	1.4	0.45	0.16
	E5544	+	1.0	1.1	0.28	1.17
	E6046	+	3.5	0.40	0.27	
	E6044	+	0.45	0.62	0.05	
Late July	E4542	–	--	–	–	–
	E5046	0.10	0.52	0.26	0.10	0.01
	E5044	0.01	0.72	0.67	0.36	0.06
	E5544	+	0.70	0.51	0.14	0.02
	E6046	0.50	1.4	0.27	0.28	0.01
	E6044	–	0.60	0.71	0.22	0.01
	E6546	0.14	0.82	0.05	0.30	0.01
Early August	E4542	–	–	–	–	
	E5046	0.05	1.6	0.34	0.08	0.22
	E5044	–	0.33	0.09	0.03	0.03
	E6046	+	1.3	0.70	0.48	0.01

APPENDIX TABLE F. AGE COMPOSITION (IN PERCENTAGES) OF SALMON IN SAMPLES FROM THE MOTHERSHIP FISHERY AND LAND-BASED REGION, BY REGION AND MONTH

(Samples from the landbased region were provided by Japanese research and training vessels fishing with 4.5″ mesh gillnets.)

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F-2.	Chum: 1955–1960	276
F-3.	Coho: 1959–1960	278

F-1. Sockeye.

Year	Month	Age 4_1	4_2	5_2	5_3	6_2	6_3	6_4	7_3	7_4	Other	Sample size
						East of 170°E						
1956	May		13	21	28		30	1		3	4	3048
	June		24	15	34		21	2		2	2	6186
	July		24	14	41		14	3		2	2	2133
						West of 170°E						
	May		8	24	19		31	4		8	6	963
	June		8	12	42		19	9		6	4	405
	July		15	7	39		21	10		6	2	2599
	Aug.		30	6	46		9	7		1	1	1776
						Okhotsk Sea						
	June		10	25	25		34	3		1	2	343
	July		8	17	27		33	4		9	2	1049
	Aug.		3	6	26		35	8		20	2	132
						East of 170°E						
1957	May		1	38	15		41	2		3	1	2176
	June	—	2	40	22	—	32	2	—	2	—	3732
	July	—	8	30	27	—	29	3	—	3	—	471
						West of 170°E						
	May		1	30	8		51	4		5	1	3163
	June		2	25	13		43	9		7	1	3684
	July	—	4	21	13	—	40	14	—	8	—	4529
						Okhotsk Sea						
	June	—	15	29	20	—	32	3	—	1	—	811
	July		3	33	13		38	8		4	1	892
						East of 170°E						
1958	May	—	2	20	13	5	51	2	3	4	—	1074
	June	—	6	17	35	3	28	5	2	4	—	1619
	Aug.	—	25	7	53	—	6	8	—	1	—	248
						West of 170°E						
	May	—	1	21	12	6	48	3	3	6	—	2880
	June	—	5	16	36	3	28	7	1	4	—	7061
	July	—	5	10	46	2	23	10	—	4	—	8343
	Aug.	—	15	4	60	—	10	10	—	1	—	1833

Continued . .

F-1. Sockeye (Continued).

Year	Month	Age 4_1	4_2	5_2	5_3	6_2	6_3	6_4	7_3	7_4	Other	Sample size
						Okhotsk Sea						
1958	June	—	14	36	45	—	5	—	—	—	—	440
(cont.)	July	—	18	23	36	4	18	1	—	—	—	611
	Aug.	—	7	26	25	13	29	—	—	—	—	146
						East of 170°E						
1959	May	6	6	19	22	—	34	8	—	5	—	541
	June	2	13	11	42	—	18	11	—	3	—	2952
	July	1	23	7	50	—	7	10	—	2	—	2295
						West of 170°E						
	May	3	3	18	19	—	41	8	—	8	—	2493
	June	2	9	10	32		26	14		6	1	5534
	July	1	13	9	33		21	17		5	1	2868
						East of 170°E, South of 52°N						
1960	May	5	10	31	16		31	3		3	1	185
	June	1	47	17	11		19	2	—	3	—	1134
	July	1	24	3	60		5	5		1	1	822
						East of 170°E, North of 52°N						
	June	1	41	15	11		27	1		3	1	2729
	July	1	36	11	12		35	—		4	1	215
	Aug.	—	27	2	66	—	3	2	—	—	—	62
						West of 170°E						
	May	4	4	34	20		29	2		6	1	1144
	June	2	5	30	26		26	3		6	2	2066
	July	2	9	10	56		11	6		5	1	4927
	Aug.	1	33	4	49	—	2	11	—	—	—	142
						Landbased, South of J-S Treaty Line						
	May	1	23	1	63	—	8	3	—	—	—	71
	June	—	5	—	45	—	27	14	—	9	—	22
						Landbased, North of J-S Treaty Line						
	July	—	11	3	63		12	7		3	1	115
	Aug.	2	10	12	36		22	4		12	2	49

F-2. Chum.

Year	Month	Age 3	4	5	6	7	Sample size
				North Pacific			
1955	May	2	59	38	1	–	543
	June	1	67	32	—		1098
	July	2	80	18	—		885
	Aug.	14	78	8	—		3378
				Okhotsk Sea			
	June	—	47	53	—	–	246
	July	1	62	37	—	–	166
	Aug.	4	64	32	—	–	115
				East of 170°E			
1956	May	—	14	83	3	–	344
	June	3	34	62	1	–	4108
	July	12	42	45	1	–	1658
				West of 170°E			
	May	—	21	78	1		934
	June	1	45	53	1	—	344
	July	16	43	41	—	—	2012
	Aug.	21	37	42	—	..	1200
				Okhotsk Sea			
	June	—	33	67	—		119
	July	9	48	42	1		284
				East of 170°E			
1957	May	1	59	28	12	–	2012
	June	6	68	21	5	–	3186
	July	29	63	6	3		273
				West of 170°E			
	May	1	61	25	13		2927
	June	6	66	20	8		3556
	July	6	75	14	5		4373
				Okhotsk Sea			
	June	3	73	15	9		860
	July	15	73	8	4		1018
				Landbased, South of J-S Treaty Line			
	June	4	55	41	—		141
	July	12	56	32	—		327
	Aug.	38	45	17	—		29
				Landbased, North of J-S Treaty Line			
	June	36	41	23	—		39
	July	26	62	12	—		254
	Aug.	44	52	4	—		72
				East of 170°E			
1958	May	—	61	37	2		1252
	June	4	72	23	1		1769
	Aug.	44	52	4	—		181
				West of 170°E			
	May	—	62	37	1		3416
	June	7	75	17	1		7844
	July	39	55	6	—		9646
	Aug.	50	46	4	—		2370

Continued . . .

F-2. Chum (Continued).

Year	Month	Age 3	4	5	6	7	Sample size
				Okhotsk Sea			
1958 (cont.)	June	14	61	25	—	—	715
	July	40	54	6	—	—	850
	Aug.	54	44	2	—	—	260
				Landbased, South of J-S Treaty Line			
	May	9	78	13	—	—	457
	June	17	77	6	—	—	935
	July	52	45	3	—	—	71
				Landbased, North of J-S Treaty Line			
	May	1	79	19	1	—	128
	June	33	60	7	—	—	586
	July	50	46	4	—	—	745
	Aug.	39	58	3	—	—	310
				East of 170°E			
1959	May	—	93	7	—	—	522
	June	2	94	4	—	—	3339
	July	11	87	2	—	—	2768
				West of 170°E			
	May	1	91	8	—	—	2571
	June	4	92	4	—	—	6297
	July	12	86	2	—	—	3288
				Landbased, South of J-S Treaty Line			
	May	1	85	14	—	—	708
	June	7	85	8	—	—	1093
				Landbased, North of J-S Treaty Line			
	June	5	90	5	—	—	312
	July	35	62	3	—	—	1242
	Aug.	43	53	4	—	—	329
				East of 170°E, South of 52°N			
1960	May	—	59	41	—	—	234
	June	1	60	39	—	—	1288
	July	26	68	6	—	—	1010
	Aug.	7	83	7	—	3	29
				East of 170°E, North of 52°N			
	May	—	8	64	28	—	36
	June	—	65	35	—	—	2721
	July	2	81	17	—	—	246
	Aug.	—	93	7	—	—	14
				West of 170°E			
	May	—	65	35	—	—	1286
	June	1	58	41	—	—	2333
	July	10	69	21	—	—	5516
	Aug.	23	65	12	—	—	181
				Landbased, South of J-S Treaty Line			
	May	5	68	27	—	—	730
	June	5	74	21	—	—	1314
	July	33	58	9	—	—	934
				Landbased, North of J-S Treaty Line			
	July	43	51	6	—	—	1139
	Aug.	51	45	4	—	—	374

F-3. Coho.

Year	Month	Age 3_2	4_2	4_3	5_3	5_4	Other	Sample size
				East of 170° E				
1959	May	25	—	75	—	—	—	4
	June	21	1	68	2	8	—	211
	July	35	—	59	—	6	—	229
				West of 170° E				
	May	8	—	75	—	17	—	12
	June	35	1	60	—	4	—	452
	July	38	1	56	—	5	—	482
				East of 170°E, South of 52°N				
1960	June	14	—	86	—	—	—	7
	July	29		65		5	1	252
	Aug.	17	—	66	—	17	—	6
				East of 170°E, North of 52°N				
	June	—		50	—	50		2
	Aug.	7		82		7	4	28
				West of 170°E				
	May	—		100	—	—		2
	June	25		69		5	1	84
	July	23		69		7	1	929
	Aug.	18	—	76	—	6	—	17
				Landbased, South of J-S Treaty Line				
	May	100	—		—	—	—	1
	June	8		84		4	4	24
	July	22		69		6	3	147
				Landbased, North of J-S Treaty Line				
	July	27		65		6	2	239
	Aug.	20		70		8	2	84

APPENDIX TABLE G. LENGTH FREQUENCY DISTRIBUTION OF MALE AND FEMALE SALMON OF DIFFERENT AGES IN SAMPLES FROM THE MOTHERSHIP FISHERY AND THE LANDBASED REGION, BY REGION AND MONTH, 1957–1960

All lengths are in centimeters.

		Page
G-1.	Sockeye—1957	280
G-2.	Sockeye—1958	284
G-3.	Sockeye—1959	289
G-4.	Sockeye—1960	295
G-5.	Chum—1957	309
G-6.	Chum—1958	316
G-7.	Chum—1959	325
G-8.	Chum—1960	331
G-9.	Pink—1957	340
G-10.	Pink 1958	343
G-11.	Pink—1959	346
G-12.	Pink—1960	348
G-13.	Coho 1957	351
G-14.	Coho—1958	353
G-15.	Coho—1959	355
G-16.	Coho—1960	357
G-17.	Chinook 1957	360
G-18.	Chinook—1958	362
G-19.	Chinook—1959	363
G-20.	Chinook—1960	364

G-1. Sockeye, 1957.

East of 170°E—May

	4_2		5_2		5_3		6_2		6_3		6_4		7_3		7_4	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
41																
2																
3																
4					1					1						
45						3			1							
6			2	1		1				1						
7	1		2	1	3	2				1	1	1				
8	2	2	1	1	4	5			3	1	1	4				
9			3	3	13	4			6	3	2				1	1
50	2	1	8	5	17	14			19	11	3	4				1
1		1	16	14	22	10			23	6	1	3			1	1
2	1		35	11	26	22			47	23	2	3			6	2
3		1	37	20	22	30			64	13	1	2			6	3
4			60	31	20	26			77	34	3	1			1	
55		1	81	59	13	25			80	47	1				7	5
6			53	43	1	7			69	44	1	2			3	5
7	1		43	37	8	3			44	44	1				2	4
8		1	46	57	2	3			53	46					1	1
9		1	32	52		3			22	34					1	3
60			9	40	2	5			17	18		1			1	
1			3	17		2			4	21						
2			3	16					4	8						
3				2	1					5						
4				2						3						
Total	7	8	434	412	155	165			533	364	17	21			30	26
Mean	50.3	52.8	55.2	56.7	52.3	53.2			54.9	56.3	51.8	51.4			54.3	55.0

East of 170°E—June

41																
2		1														
3																
4																
45					1	1									1	
6	1	1								1						
7	1	1	2	2	5	4										
8		1	4	7	10	10					2	1				
9	5	2	6		15	10			3	2	1	3				
50	6	1	3	4	57	34			4	5	9	3			1	
1	3	5	10	7	52	26			10	9	5	3			1	
2	6	4	20	9	61	45			16	13	2	7			2	
3	5	2	28	13	66	51			27	13	4	4			2	
4	2	2	55	30	43	49			47	24	4	4			3	3
55	1	2	102	33	40	65			81	32	1	2			7	4
6	4		114	43	24	25			104	33	2	1			5	2
7	2		140	41	26	28			91	42	3				8	5
8	1	1	144	67	7	17			96	45					5	2
9	1	1	92	67	7	13			79	41					3	3
60		1	78	58	3	8			80	45					5	3
1			25	55		1			41	41		1			6	2
2			17	43		1			13	29		2			1	2
3			7	34					11	25					1	2
4			7	24					4	19						1
65			8	13		1			3	11						1
6				5					2	7						
7			1	5					1	1						
8										2						
9				1												
70										1						
Total	38	25	863	561	417	389			713	441	33	31			51	30
Mean	52.3	51.8	57.0	58.7	52.8	53.8			57.2	58.5	52.1	52.9			56.8	58.4

Continued . . .

G-1. Sockeye, 1957 (Continued).

East of 170°E—July

	4_2		5_2		5_3		6_2		6_3		6_4		7_3		7_4	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
41																
2																
3																
4																
45		1														
6		1			2	1						1				
7	1	3			1	5					1					
8	5	3		1	5	7										
9	4	4	3		7	9										
50	2	2	2	2	8	12				2	1	1				
1	4	3	1	3	4	11			2	2	3	1				
2		2	4	2	10	6			3	4						
3		1	7	3	8	4			2	3		2			1	1
4		1	10	5	9	6			4	1					1	1
55			11	8	2	2			15	5		1				
6			9	2	1	1			8	6						1
7			7	5		1			8	8		1			2	2
8			9	3	1	2			11	5						
9			9	10		2			16	4					1	
60			6	1					5	8					1	1
1			5	7					2	3						
2				2						2						
3				2					1	2						
4				1					1	2						
65				3						2						1
6			1		1											
Total	16	21	84	60	59	69			78	59	5	7			6	7
Mean	49.2	49.3	56.1	57.2	51.6	51.1			56.9	57.4	50.0	52.1			56.6	57.4

West of 170°E—May

41					1											
2	1															
3																
4											1					
45	2			1	2	1						2				
6	2	3			6	2			3	1	3					
7	1	2	2	1	6	4			2	3	5	1				
8	2	2	4	2	8	7			6	8	6	1				
9	2	2	11	8	8	13			20	6	4	7			3	
50	4	4	28	13	18	20			58	27	11	19			2	2
1	1	4	51	16	10	24			96	26	2	9			8	3
2	3	4	53	5	15	12			117	33	4	6			17	3
3		1	79	22	16	9			156	52	6	5			16	6
4	1		84	27	10	11			145	68	2	5			15	10
55	1		81	51	3	14			132	80	3	3			14	2
6	2		54	55	1	4			55	82	2	2			4	11
7			41	54	1	2			48	70		2			4	8
8			23	53		1			26	58		1			3	4
9			12	34	1	2			15	41					2	1
60			7	27		1			6	30						4
1			2	10					2	11						
2				2					1	4						1
3			1	1						3						
4				2						2						
65																
6																
7																
8																
9																
70										1						
Total	22	22	533	384	106	127			888	606	49	63			88	73
Mean	49.7	49.6	54.0	56.0	50.8	51.6			53.5	55.4	50.3	51.3			53.5	55.2

Continued

G-1. Sockeye, 1957 (Continued).

West of 170°E—June

	4_2		5_2		5_3		6_2		6_3		6_4		7_3		7_4	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
41																
2											1					
3					1											
4					3	3					1	1				
45	1	1	1	1	2	3					1	1				
6	4	5	3	1	5	7				1	2	1				
7	2	2	1	1	7	18			1	1	4	4				
8	3	4	5	3	11	25			7	5	9	8			1	1
9	4	3	11	6	28	38			7	3	15	10			3	2
50	4	5	18	9	34	48			22	10	29	33			3	2
1	11	11	25	13	23	40			47	23	23	32			8	3
2	2	3	28	18	24	24			70	42	8	33			9	3
3	2	5	76	20	13	26			131	53	16	19			24	6
4	3	3	104	32	13	20			191	64	8	15			21	11
55	1		124	35	6	10			182	77	1	8			24	14
6		1	53	50	4	7			102	95	1	2			23	15
7		1	41	41	2	4			67	79	3	3			15	20
8			14	54	3	2			39	61	1	1			7	11
9			7	41		1			19	39	1	3			4	10
60			2	36					5	23		1			1	11
1			1	7					3	12						3
2			1	6					4	8	1					2
3			1	2						2						
4				1						1		1				1
65										3						
6										1						
Total	37	44	516	377	179	276			897	603	125	176			143	115
Mean	50.0	50.3	54.1	56.2	50.7	50.7			54.4	55.7	50.9	51.7			54.5	56.

West of 170°E—July

41																
2																
3																
4					4	1				1						1
45	2	1			2	3				1	4	2				
6	5	4	2	2	6	7			2	2	5	5			1	
7	1	1	2	2	7	15			2	6	13	10			2	
8	5	5	12	3	24	29			6	8	20	27				1
9	6	5	14	4	29	29			12	9	30	39			2	1
50	7	6	21	15	52	44			24	12	59	50			2	2
1	1	3	19	23	34	43			35	19	48	42			7	4
2	4	4	32	15	29	43			55	34	31	44			11	9
3	3	6	46	24	18	27			72	51	25	44			12	15
4	2	3	53	33	13	14			145	62	17	22			25	14
55	2	2	107	31	15	20			256	78	10	15			40	15
6		2	86	35	11	17			199	101	5	7			50	12
7	1		61	35	4	7			139	77	6	11			30	18
8			45	32	5	6			72	65	5	3			18	9
9	1	1	16	31		3			29	63	3	1			7	4
60		1	9	38	3	3			19	53		2			5	9
1			3	28					9	14		1			1	6
2		1	2	16					8	19		1			1	5
3			2	8					2	7						2
4				5					1	3						
65												1				2
6				2						2						
7										1						
Total	40	45	532	382	256	311			1,087	688	281	327			214	129
Mean	50.1	51.2	54.8	56.5	51.1	51.4			55.2	56.0	51.0	51.5			55.3	55.

Continued . . .

G-1. Sockeye, 1957 (Continued).

Okhotsk Sea—June

	4_2		5_2		5_3		6_2		6_3		6_4		7_3		7_4	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
41																
2																
3																
4		2														
45																
6					1											
7		2			1							1				
8	4	3		1	5	2						1				
9	3	7			11	5			1	1						
50	10	6	1	2	13	8			3	1		2				
1	5	10	2	2	8	11			2	2	3					
2	2	11	7		6	9			10		1	2				1
3	4	7	8	5	6	13			11	4	2	2				1
4	1	13	15	5	6	13	1		25	7	1	2				1
55		14	23	4	2	17			28	4		4				1
6	1	13	18	14	1	6	1		12	20					2	
7		3	36	12		5			19	15		1	1			
8			13	6		3			15	9		1			2	
9			12	10		2			13	8		1				
60			1	14		1			8	6						
1			3	4					4	9			1			1
2			1	4						8						
3				6					1	5						
4				3						5						
65				2				1		3						
6				1						1						
Total	30	91	140	95	60	95	2	1	152	108	7	17	2		4	5
Mean	50.7	52.7	56.0	58.0	50.8	53.4	55.0	65.0	55.7	58.1	52.1	53.4	59.0		57.0	55.0

Okhotsk Sea—July

41																
2																
3																
4																
45																
6												1				
7																
8	2				1	2						2				
9	1			1	3	3			1			1				
50	1	2			9	7			3		7	7				
1	1	2	1	1	10	10			2	1	6	5				
2	2	2	2	2	13	2			11	4	8	4				
3	6	1	5	2	9	7			15	4	4	4			1	1
4	1	4	25	1	4	10			31	9	2	7			4	1
55	1	2	39	3	4	5			52	7		5			1	
6		1	40	6	2	5			48	13		2			5	
7	2		51	6	3	2			42	13		2			5	2
8			32	6		1			28	21		2			4	1
9			13	14			2		14	8						5
60			10	8			2		2	6					2	1
1				13		1			1	4						
2				7						7						
3			2	2												
4				1												
65				1						1						
Total	17	14	220	74	58	55	4		250	98	27	42			22	11
Mean	52.4	52.9	56.4	58.7	52.2	52.8	59.5		55.7	57.2	51.6	52.6			56.4	57.6

G-2. Sockeye, 1958.

East of 170°E—May

	4_2		4_3		5_2		5_3		5_4		6_2		6_3		6_4		7_3		7_4		8_4	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
41																						
2																						
3		1																				
4							1	1														
45																						
6		1					1	3							1	1						
7		2					2	5														
8		1				2	2	3					1	2	1							
9	1	1			1		8	4					3	2								
50	1	1			4	2	9	13					9	3	1				1			
1		2			10	5	5	20					22	1	2	2						
2		5			1	4	9	19					37	8	1	1	2		2			
3	1				12	2	5	3				2	51	10		2		1	4	2		
4					23	10	4	8			6		59	17	3	1	2	1	4	1		
55					25	7	1	2			3		49	19	1	1	3		4	3		
6					21	6	1	3			9	1	36	26			3	2	3			
7					14	7	1	1			11	2	22	34			2	1	5	3		
8					13	13		1			2	1	20	22			3	1				
9					4	10						2	16	28			5		1	2		
60					3	10					3	2	5	21			1	1		2		
1					1	5		1			2	4	3	14				3		2		
2					2	2							3	5				1				
3						2						1		2				2		1		
4														4								
65														2								
6													1									
Total	3	14			134	87	49	87			36	15	337	220	10	8	21	13	24	16		
Mean	50.7	49.4			55.2	56.6	50.9	51.3			56.6	58.6	54.6	57.1	51.6	52.0	56.6	58.8	54.8	57.4		

East of 170°E—June

41																						
2																						
3																						
4		1						1														
45								1														
6	1	1					2	3														
7	1	2					4	5							1							
8	1	5				2	13	3					4		2	4			1			
9	8	2			3	1	25	15			1		2	1	2	3						
50	15	7			2	1	58	40					4	2	5	3			1			
1	8	4			1	2	60	45					3	3	13	8		1				
2	7	4			6	6	46	58			1		11	6	10	5			1	1		
3	5	6			19	5	28	45			2	1	17	8	10	7			2	1		
4	4	3			19	6	14	44			1		19	14	3	2		1	5	3		
55		1			31	7	8	16			2	1	37	14	3	3			8	2		
6		1			36	4	6	12			6		46	17		1	1	1	8	4		
7		2			24	11	4	5			9		32	22			2	1	6	5		
8		1			20	9	1	7			7	1	31	25		2	4		5	2		
9	2				10	10		2			3	3	29	22		1	7	1	6	1		
60					10	9	2				4	2	16	13			2		1	1	1	
1					2	5	1						6	18			1			3		
2						6	1				1		1	8								
3						4						1		6		1		2				
4					1	2						1	1	2				2				
65						2								3								
6						1								2								
7														1								
Total	52	40			184	93	273	302			37	10	259	187	49	39	17	9	44	23	1	
Mean	51.0	51.2			55.8	57.4	51.4	52.2			56.9	59.0	56.1	57.7	51.7	52.1	58.6	59.0	55.9	56.7	60.0	

Note: No data for East of 170°E-July.

Continued . . .

G-2. Sockeye, 1958 (Continued).

East of 170E°—August

	4_2		4_3		5_2		5_3		5_4		6_2		6_3		6_4		7_3		7_4		8_4	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
41																						
2																						
3																						
4																						
45																						
6	1						1															
7	2						1	2								3						
8	4	5					2	3							1	1						
9	3	3				1	9	5							2	2						
50	5	3			1	1	7	8					1			1						
1	4	7					10	13							1							
2	1	5					4	18								4			1			
3		7					3	13					1	1	1	3				1		
4		7					1	13			1					1						
55		4				1	1	11						2	1							
6					1	3		1						3						1		
7		2			1	1							1									
8						3	1	1														
9						2								3								
60						1							1									
1						1																
2													1									
3								1														
Total	20	43			3	14	40	89			1		5	9	6	15			1	2		
Mean	49.3	52.0			54.3	56.6	50.6	52.3			54.0		56.4	56.4	50.8	50.5			52.0	54.5		

West of 170°E—May

41																						
2																						
3							1															
4																1						
45		1						1														
6	1	1					2	1														
7	2	1				1	4	8					1						1			
8		1			1		7	5							1	1						
9		2			3		13	12					6	1	1	1			2			
50	1	5			9	3	13	36				1	23	10	2	8			2			
1	3	7			20	5	22	60		2	1	47	12	6	5	1		5	2			
2		6			38	11	10	55		3	1	80	23	6	10	1	1	10	4			
3	1	2			42	11	11	26		7		117	42	2	9	3		9	3			
4	1	2			72	12	9	12		14	1	150	47	2	7	6	5	16	8			
55		1			63	34	3	14		18	2	136	91	1	5	8	3	17	8			
6		2			48	33	1	5		23	6	94	83	1	1	12	4	15	13			
7	1	1			29	50	1	1		29	6	51	83	1	1	10	3	7	11	1		
8					11	39	1			19	7	38	84		1	12	2	3	10			
9					12	21	1	2		7	7	13	34			3		2	7			1
60					6	24				4	6	8	59			1	3	1	3			
1						10				3	8	3	24				2		1			
2						4					4	2	16						1			
3						2					3		2			1		1				
4											1						2					
65						1					2											
6																	1					
Total	10	32			354	261	99	238		129	56	769	611	23	50	58	26	91	71	1	1	
Mean	50.7	51.3			54.4	56.8	51.0	51.5		56.2	58.8	54.3	56.5	52.0	52.3	56.3	57.5	54.4	56.2	57.0	59.0	

Continued.

G-2. Sockeye, 1958 (Continued).

West of 170°E—June

	4_2		4_3		5_2		5_3		5_4		6_2		6_3		6_4		7_3		7_4		8_4	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
41																1						
2																						
3		1				1		1														
4	1	1					1	2														
45	2	7			1		2	6						1	1	1						
6	1	10					5	13						1	4							
7	9	22			3	1	33	23					1	1	7	3						
8	15	19			1		76	56					3		13	8						
9	23	16			7	1	182	96					3	2	16	15			1			
50	39	21			16	6	270	192					32	13	45	31				2		
1	19	29			19	16	221	220			1	1	44	10	48	41	1		6	1		
2	11	19			44	15	167	247			2		76	31	37	34	1	2	6	2		
3	7	22			57	15	109	204			1	1	125	55	32	33	1	1	21	7		
4	4	11			108	24	51	140			17	1	195	54	17	37	1	1	25	9		
55		10			134	16	27	93			13	2	236	83	8	26	8	1	35	19		
6	1	5			121	37	13	51			23	5	203	86	2	12	7	5	29	7		
7	1	3			106	49	3	19			23	1	169	81	1	6	8	1	24	21		
8					88	45	2	4			29	6	90	72	2	2	9	2	11	8		
9	1				44	44	3	5			24	4	63	82		4	7	2	8	6		
60					17	39		2			14	6	17	64	1		5	1	4	12		
1					11	35					7	4	9	38		2	3	1		2		
2					4	13		2			3	4	3	21				3		2		
3					1	8		1				7	1	12						1		
4					1	9						2		4				1		3		
65						2						3	1	2				1		1		
6						1						2										
7												1										
8												1										
9																						
70																						
77																		1				
Total	134	196			783	377	1,165	1,377			157	51	1,271	713	234	256	51	23	170	103		
Mean	50.5	50.4			55.5	57.4	50.8	51.8			57.3	60.2	55.1	56.7	51.2	52.4	57.2	58.7	55.3	56.8		

West of 170°E—July

41																						
2			1																			
3	1	1	1					1	1													
4			1				3		1													
45	3	3					9	9							2	1						
6	7	7	1				23	11							2	1						
7	9	15			1	1	60	42							11	29						
8	12	35			2	1	124	93			1		3		27	18			1			
9	24	43			2	1	137	151			2		7	4	22	25						
50	21	38			5		291	255					10	1	57	42				2		
1	18	41			23	6	316	243				2	18	11	64	55			2	1		
2	13	27			13	10	374	268			2		18	22	84	45			4	2		
3	15	16			19	9	287	231			2		36	25	73	39			6	1		
4	9	14			28	15	200	182			1	2	69	37	59	45			9	2		
55		11			63	17	100	151			8		99	45	32	36			22	7	1	
6	2	7			72	22	40	99			9		184	50	15	14			33	14		
7	2	7			84	24	16	59			14	2	239	91	9	17	2	2	30	18		
8		5			79	20	6	41			17	4	214	72	4	7	4		28	11		
9		1			46	24		11			20	2	150	75		3	8	2	26	17		
60					38	42	3	3			18	4	73	62	1			1	27	16		
1		1			13	27	1	3			10	2	40	64		1	3	2	8	14		
2		1			11	31		1			6	3	19	59		1	3	3	5	15		
3					4	28		1			1	9	1	38		1		1	1	6		
4						19	1	1				5	5	24			1			2		
65						8					1	6	2	14				2		2		
6						5						7		9				1				
7						1						3		2		1						
8														1								
Total	136	273		4	503	311	1,991	1,856		2	112	51	1,187	706	462	381	21	14	202	130	1	
Mean	50.2	50.8		43.8	56.6	59.0	51.5	52.1		43.5	58.1	62.0	57.0	58.4	52.0	52.1	59.6	61.3	57.3	58.7	55.0	

Continued . . .

G-2. Sockeye, 1958 (Continued).

West of 170°E—August

	4_2		4_3		5_2		5_3		5_4		6_2		6_3		6_4		7_3		7_4		8_4	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
41	1																					
2		1						1														
3																						
4		1					1	1														
45	2	2		1			2	2		1					1							
6	3	4		1			10	8							2	2						
7	9	11					35	14							5	1						
8	9	25			1	1	55	25			1		2	1	11	1						
9	9	31				1	60	56							13							
50	11	26			2		85	80					3	2	10	14						
1	10	46			2	1	76	94			1		8	3	12	21			1	1		
2	10	26			2	3	62	107				1	3	5	9	22	1	2	1	1		
3	3	16			9	2	45	76					10	7	7	6						
4	2	12			3	7	31	55				1	8	12	9	10		1				
55	4	6				4	14	39					5	10	5	6			2	1		
6					3	6	4	12					12	10	3	3		1	2	1		
7		3			7	6		6				1	16	9	1	2	1		4			
8		1			4	4	3	2					10	6					5			
9					2	3	2	1				1	12	6					1			
60	1				2	1							10	3								
1					2								7	2								
2						1					1		2	3			1					
3											1											
4													1	1								
65																						
6														1						1		
Total	74	211		2	39	40	485	579		1	4	4	109	81	88	88	3	4	16	5		
Mean	49.9	50.5		45.5	55.2	55.4	50.5	51.5		45.0	56.0	55.5	56.3	55.8	50.8	52.0	57.0	53.5	56.4	56.0		

Okhotsk Sea—June

41																						
2		1																				
3	1	1																				
4	1	2																				
45	2	2					1															
6	4	2					5	3														
7	1	2					10	1														
8	2					1	17	8														
9	3	4			1		17	13														
50	3	5			3	3	14	26														
1	2	3			7	2	18	30														
2	4	7			11	4	5	20						1								
3	2	3			23	4	1	5						2								
4	1	2			24	3	2	1						1								
55					14	6	1						1	3								
6					8	4							1	2								
7					9	4								2								
8					7	7																
9					4	5							3									
60					1	2							1	1								
1					1	2							1									
2													1									
3													2									
Total	26	34			113	47	91	107					10	12								
Mean	48.9	49.4			54.3	55.5	49.3	50.4					59.7	55.3								

Continued

G-2. Sockeye, 1958 (Continued).

Okhotsk Sea—July

	4_2		4_3		5_2		5_3		5_4		6_2		6_3		6_4		7_3		7_4		8_4	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
41																						
2																						
3		1																				
4																						
45																						
6		2																				
7		1																				
8	2	2					3	1														
9	7	4					13								1							
50	12	2				1	20	4			1		1									
1	12	5				1	18	10					1									
2	17	6			2		34	7					1	1								
3	11	7			3		25	12						2								
4	5	6			6	1	12	18					3									
55	2	3			9	4	10	14				1	7	5	2							
6	1	1			11		2	5				1	8	5	1							
7	1	1			17	7	1	6			1		9	8								
8					9	1		2			1		9	4	1				1			
9		1			10	7	1				1		9	5								
60					8	6					6		9	4								
1		1			6	8					3	2	3	4								
2					2	7					4		1	6					1			
3						4						1		1								
4						5						3		1								
65						3								1								
6																						
7														1								
8																						
9																						
70						1																
Total	70	43			83	56	139	79			17	8	61	48	5				2			
Mean	51.6	52.0			57.2	60.1	51.9	53.6			59.7	61.0	57.4	58.6	54.6				60.0			

Okhotsk Sea—August

41																						
2				1																		
3																						
4																						
45																						
6																						
7																						
8																						
9																						
50							3															
1	2						2	1														
2	1						2															
3					1		4	2														
4	2	2					9	2						1								
55	1	2			2		5	2			1			1								
6					2		1	1					7	2					1			
7					4	2	1	1			2		3	2								
8					7	1					1		4	3								
9					5	2					3	1	3	2								
60					3						3	1	4	2								
1											2											
2						3					3			1								
3					1	1					1			2								
4						2						1	1	1								
65														1								
6						2								1								
Total	6	4		1	25	13	27	9			16	3	22	19					1			
Mean	52.8	54.5		42.0	57.9	61.5	53.4	54.2			59.7	61.0	58.0	59.5					56.0			

East of 170°E—May

	3_1		4_1		4_2		5_1		5_2		5_3		6_2		6_3		6_4		7_3		7_4		7_5		8_4		8_5	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
41																												
2												1																
3																												
4																												
45												1																
6																	1											
7																												
8					2						2	3																
9					2	1					8				1		3	2										
50					4				1	3	7	4				1	5	3			2							
1			1		3	2			4	1	7	7			1		4	1										
2				1	1	3			5	3	10	6			6	4	4	3										
3				1	1	1			7		7	7			9		6	2			1	1						
4			2	2		3			7	5	4	7			16	1	3	2			3							
55			6	1	3	2			17	1	4	9			25	5		2			4	1						
6			5	1					13	3	3	6			23	4		2			2	1						
7			4			4			3	2	1	6			20	5						2						
8			4	3		1			9	3	3	2			21	4			1		2	1						
9			1	1					3	4	1	1			5	5					1	1						
60				1					2	4		2			4	5					2	3						
1												1			2	5												
2										2					1	2						1						
3				1												2												
4										1												1						
Total			23	12	16	17			71	32	57	63			134	43	26	17	1		17	12						
Mean			56.0	56.7	51.1	54.0			55.2	56.3	52.3	53.6			55.9	57.6	51.5	52.4	58.0		55.4	58.4						

Continued . . .

G-3. Sockeye, 1959 (Continued).

East of 170°E – June

	3_1		4_1		4_2		5_1		5_2		5_3		6_2		6_3		6_4		7_3		7_4		7_5		8_4		8_5	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
41																												
2												1																
3					1																							
4	1					3					1							1										
45					1	3					6	3					3											
6					2	15					5	5			1	1	3											
7		2			9	16			3	1	20	11			1	1	3	4										
8			1	1	14	31			2		35	40			1	1	7	6										
9	1		4	1	13	46			4	1	41	74			7	2	8	23				1						
50		1	5	1	14	33			18	9	79	88			11	4	23	19			1	1						
1				1	24	26			14	6	65	85	1		7	5	22	18			4							
2			1	3	8	28			19	4	96	98			12	8	27	24			3	1						
3			6	3	12	17			20	3	74	79			25	8	34	16			5	8						
4			5	3	12	24			19	9	51	46			27	13	12	16			2	1						
55			7	8	6	13			25	4	33	54			46	11	6	13			8				1			
6			9		2	9			22	5	14	45	1		46	9	12	11			8	6		1	1			
7		1	5		2	5			29	4	7	24	1		45	12	2	5			16	3						
8			1	2		2	1	1	13	10	4	18	1		52	24	1	3			8	1						
9					1	1			14	1	3	7			39	14	3	3			3	5						
60			1		2	1			11	8	1	6			25	11		1			2	2						
1									1	4	1	2			11	9		1										
2									4	9	1				6	8						1						
3				1					1	1					3	9												
4				1					1	2					1	2												
65										2					1	2												
6															1	2												
7				1																		1						
8																												
9																1												
Total	2	4	45	26	123	273	1	1	220	83	537	686	4		368	157	166	164			60	31		1	2			
Mean	46.5	50.3	53.9	54.9	51.0	50.6	58.0	58.0	54.8	56.3	51.6	52.1	55.5		56.3	57.2	51.9	52.2			55.3	56.1		56.0	55.5			

Continued . . .

G-3. Sockeye, 1959 (Continued).

East of 170°E—July

	3_1		4_1		4_2		5_1		5_2		5_3		6_2		6_3		6_4		7_3		7_4		7_5		8_4		8_5	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
41																												
2												1																
3																												
4					1						2	2																
45					7	5					4	4																
6					7	8					21	16					3	1										
7					14	21					35	26	1				4	2										
8		1			30	33					60	55			2		8	11			1							
9					26	55			3		51	62			1		9	17			2							
50			1		26	91			2	2	84	112		1	4	1	9	20										
1			1		16	48			2		67	107			1		7	15				1						
2				1	13	39			9	9	53	90			4	2	14	20										
3				2	7	30			5	5	41	53			1	3	11	13				1						
4					5	20			3	3	33	33			3	5	10	10				2						
55					5	10			3	7	15	33			6	7	9	19										
6					1	5			11	4	13	12	1		8	4	8	5			2	1						
7			1			3			10	6	1	12			11	6	2	2			6	1						
8									9	8	1	11			15	6	2	2			4						1	
9			3			4			15	6	1	4			21	6	1	3			5	2						
60			1	1					5	6	1	5	1		14	5		1			1	4						
1						1			7	7	1	2			7	1					3	1						
2				2						3	1		1		4	7	1					2						
3									1	1					3	6						3						
4										2						4												
65										2						1						1						
6										3						1												
7						1																						
8																1												
9																1												
Total		1	7	6	158	375			85	74	487	642	4	1	105	67	98	141			24	19					1	
Mean		48.0	56.4	47.0	49.5	50.7			56.4	57.5	50.5	51.1	56.2	50.0	57.5	58.7	52.1	52.0			57.1	59.1					58.0	

Continued . . .

G-3. Sockeye, 1959 (Continued).

West of 170°E—May

	3_1		4_1		4_2		5_1		5_2		5_3		6_2		6_3		6_4		7_3		7_4		7_5		8_4		8_5	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
41																												
2																												
3						1																						
4																												
45											1																	
6												1																
7						1					3	1																
8					5	2					8	4			4		2	2					1					
9					4	1			2		17	11				1	9	2	1			2						
50			1		8				4	3	47	29			8	2	22	6			2							
1					4	2			5	2	28	45			9		10	14			2							
2			3		6	9			6	7	26	42			8	5	16	16			2	2						
3			1	2	1	11			27	8	25	47			33	24	14	22			5	4						
4			11	5	2	8			38	12	16	30	1		68	19	3	9	2		6	3						
55			11	3	3	5			57	14	7	28	2		132	40	6	16	2		32	7					1	
6			13			1			49	13	4	20	3	1	145	26	2	5	1	3	28	10			1			
7			2	1	2	2			44	9	3	5			124	36	3	3	2		23	7						
8			7	2		1			36	26	1	2	1		85	32	2	1	1		10	11			1			
9			2	2					9	25	3	3			53	47	1				6	13			1			
60			1	3					8	6	1	4	1	1	20	47		2	2	1	3	8						
1				1					1	12				2	10	25			1			2						
2									2	10					4	9					1	4						
3										4				1		3						3						
4																2			1									
65										1																		
6																												
7														1														
Total			52	19	35	44			288	152	190	272	8	6	703	318	90	98	13	4	120	76	1		3		1	
Mean			55.5	56.5	51.2	52.8			55.6	57.3	51.6	52.7	56.2	61.3	56.1	57.5	51.9	53.1	56.9	57.0	55.9	57.4	48.0		57.6		55.0	

Continued . . .

G-3. Sockeye, 1959 (Continued).

West of 170°E—June

	3_1		4_1		4_2		5_1		5_2		5_3		6_2		6_3		6_4		7_3		7_4		7_5		8_4		8_5	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
41					1						3	1																
2					1																							
3											3	1						1										
4					1	2					4	1																
45		1			6	9					6	6					3	1										
6					8	18					13	18			1		3	3										
7		2	1		7	32			2	1	21	27			1	2	4	5			1							
8			1	1	14	50			1	2	39	61			3	2	15	12										
9		2	3	1	19	46			8	3	62	78			7	2	22	20				1		2				
50			5	3	29	45			15	4	139	124		1	12	4	51	30			2	3						
1			6		14	33			11	7	123	105			13	7	74	53			5	2						
2			6	3	23	27	1		14	9	133	117			22	10	87	51			3	2	1					
3			12	7	11	20			22	10	122	121			45	15	67	45			8	2		1				
4			8	9	9	23			24	12	57	109			61	19	24	53	1		18	7	1					1
55			8	1	2	12			57	10	36	93	2		129	32	18	40	1		31	4				1		
6			6	2	2	5			62	15	14	72	1		164	27	9	23	3		38	9						
7			10	1	1	5	1		63	15	6	29			185	32	4	19		1	49	8						
8			6	4	1	5			58	9	10	18			154	52	1	7	1		35	16						
9			3	3		2			40	19	2	6	1		112	42	1	2	3	1	17	13		1				
60			4	1	1	3	1		15	17	2	8			84	59	1	1		1	17	12				1		
1			1	1					6	11	1		1		29	32				1	5	16			1			
2				4						8		1			11	19			1	1		7						
3				1					1	6					2	25						6						
4									2	5					1	6						2						
65										2						8	1			1		1						
6													1							1								
7										2						1				1								
8																2												
Total		5	80	42	150	337	3		401	167	796	996	6	1	1,036	398	385	366	10	8	229	111	2	4	1	2		1
Mean		47.4	54.4	55.4	50.2	50.2	56.3		55.9	57.1	51.3	52.1	58.6	50.0	56.7	58.1	51.8	52.7	57.4	62.1	56.4	58.2	53.0	52.5	61.0	57.5		54.0

Continued . . .

G-3. Sockeye, 1959 (Continued).

West of 170°E—July

	3_1		4_1		4_2		5_1		5_2		5_3		6_2		6_3		6_4		7_3		7_4		7_5		8_4		8_5	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
41																												
2																												
3					1																							
4					1	1					2	2																
45					7	4					4	1						2										
6		1			9	3				1	9	4					5	1										
7		2			13	21			1	1	26	16			1		6	4										
8		3	1		11	39			2	1	31	33			2		20	18										
9			1	1	12	34			6	1	36	58			1	1	26	17			1							
50	1		2	1	15	60			3	4	49	79			4	2	20	38										
1	1	1	3		12	40			3	6	42	66			6	8	15	28				1						
2	1	1			6	25			8	2	38	77	1		3	4	29	36				2	1					
3	1		1	2	9	19			3	6	49	80			14	6	27	26			1	1						
4			2	4	5	10			3	7	37	41			12	5	27	24	1		2							
55			1		4	4			18	6	36	43			10	7	20	13			5	2						
6			2	1	1	4			10	12	9	17			30	13	13	14			10							
7			1		1	5			16	11	9	23			48	12	7	16			12	2						
8		1	5						18	8	8	12	1	1	84	21	4	8		1	17	5						
9				1		1			13	7	1	8			51	7	2	8			11	4						
60									12	10	4	6	1		69	26		3	2		25	4				1		
1			1			1			5	6	1	3		1	42	16					12	4			1			
2									4	8			2		11	20				2	4	6						
3									2	10					3	26			1		2	4						
4										6		1		1	2	6	1				2	5						
65									1	4		1		1	3	11					1	6						
6										1												1						
7																2												
8																												
9																1												
70																												
Total	4	9	20	10	107	271			128	118	391	571	5	4	396	194	222	256	4	3	105	47	1		1	1		
Mean	51.0	44.5	54.3	53.6	49.5	50.3			56.4	57.7	51.5	52.1	58.8	62.0	58.0	59.3	52.0	52.4	50.9	60.6	58.7	60.5	52.0		61.0	60.0		

East of 170°E, South of 52°N—May

	3_1		4_1		4_2		5_1		5_2		5_3		6_2		6_3		6_4		7_3		7_4		7_5		8_3		8_4	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
38																												
9																												
40																												
1																												
2																												
3																												
4																												
45																												
6																												
7																												
8											1	1					1											
9						2					1	1					1											
50						2						2																
1					1	1			2			7																
2			2			1			1		1	2			1	1		1										
3						2			3			3				1		1										
4			1			3			6	1	3				2	1												
55						3			4		1	2			3	1						1						
6				1		2			5	2		3			8						1	1						
7						1			2	3					2	3		1		1								
8			1	2					2	4					7	2												
9				1					2	2	1				2	3						1						
60				2		1			2	4					6	2												
1										2					4	2					1							
2									1	1						1												
3									1	3						3												
4									1	2						1												
65										2						1												
6																												
7																												
8															1													
Total			4	6	1	18			32	26	8	21			36	22	2	3		1	2	3						
Mean			54.0	58.5	51.0	53.5			56.1	59.9	50.4	52.1			57.9	59.1	48.5	54.0		57.0	58.5	56.7						

Continued . . .

G-4. Sockeye, 1960 (Continued).

East of 170°E, South of 52°N—June

	3_1		4_1		4_2		5_1		5_2		5_3		6_2		6_3		6_4		7_3		7_4		7_5		8_3		8_4	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
41																												
2																												
3																												
4																												
45																												
6																												
7					5	2			1		1																	
8					5	2				1	2				1													
9					11	7					5	2					1											
50					23	20				1	5	1					1					1						
1			1		19	25			1	1	7	10			1	1	2	1				1						
2					11	41			5	2	5	10			3	1	1	1			1							
3					16	40			10	3	7	13			8	2		2			2	1						
4			1	1	17	58			11	1	3	17			6	2	2	2			1	3						
55			1	1	6	55			19		2	9			18	7	1	1			1	1						
6			2		4	23			17	4	4	4			12	5	1	1			3							
7			2		3	21			15	8	1	7	1		21	5		2			6							
8					5	6			11	10		4			25	4					2	1						
9						5			12	10	1				15	14			1		2	1						
60			2	2		2			4	14					11	7					3	3						
1					1				1	6					7	10						1						
2									1	12					3	20					1							
3				1		1				2					1	2						1						
4										4																		
65										2						3												
6																2												
7															1													
8															1													
Total			9	5	126	309			108	81	43	77	1		134	85	9	10	1		22	14						
Mean			56.2	58.4	52.0	53.6			56.0	59.0	52.0	53.7	57.0		57.2	59.4	52.4	54.2	59.0		57.0	56.6						

Continued . . .

G-4. Sockeye, 1960 (Continued).

East of 170°E, South of 52°N—July

	3_1		4_1		4_2		5_1		5_2		5_3		6_2		6_3		6_4		7_3		7_4		7_5		8_3		8_4	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
40												1																
1																												
2																												
3											1	1																
4											1																	
45					2						9																	
6	1				2	1					6	5																
7					9	10					24	15					2											
8		2			13	23					20	19					2											
9		1			12	21					25	37					1	2										
50		1			10	39				1	27	61				3	2	3										
1		1			6	23			1		18	59				1		4										
2			1		2	14					16	47				1	1	4			1							
3					1	7			1		5	29			2	1	1	3										
4					2					1	4	15				1	2	3										
55				1		2			2	1	7	14			1		4	2										
6						1			3		4	5			5	1	2	2			2							
7			2						3	1	1	4			1	1				1	1							
8			2	1					5			2			5	1												
9									2		1	3			5	2					1							
60			1						1	1		2			2	1												
1						1									6						1							
2									1						2													
3				1												1												
4									1						1													
65																1						1						
Total	1	5	6	3	59	142			20	5	169	319			30	15	17	23		1	6	1						
Mean	46.0	49.2	57.0	58.7	48.9	50.0			57.4	55.2	49.6	51.0			58.6	55.8	52.0	52.3		57.0	56.8	65.0						

Continued . . .

G-4. Sockeye, 1960 (Continued).

East of 170°E, North of 52°N—June

	3_1		4_1		4_2		5_1		5_2		5_3		6_2		6_3		6_4		7_3		7_4		7_5		8_3		8_5	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
40					1	1																						
1																												
2																												
3					1																							
4																												
45										1																		
6					2	1						1																
7					10	1					1																	
8					15	6					2	2																
9			1		40	14			1	1	3	7			1			1			1							
50					71	35			2		7	7			1		1	1										
1					55	67			1	1	13	6			1	1	2	1										
2				1	75	90			8	6	20	13			2	4	3	1										
3			1		46	123			10	1	19	20			10	2	1	2			1							
4			1		26	122			12	3	16	21			9	3					1	3		1				
55			1		12	111			20	9	10	27			20	10	2	4			3							
6			1	1	8	84			28	9	13	23	1		49	10	2	3			4	1	2	1				
7					11	50			35	6	5	18			69	4					8		1					
8				1	4	35			37	14	2	10			73	22		2			8	1	1					
9			2	1	5	13			31	18	2	10			101	22	1	1			8	2						
60			2	1	4	4			39	22		3	1		80	33					9	2					1	
1			2	1	2	3			15	15	4	2	1		42	31			1		5	4						
2					1	1			8	10		1			30	24					6	4						
3						3			4	15	1	1			10	22		1			1	2						
4						2			2	9		2			5	15					2							1
65						1			2	12	1				3	11						1						
6										1					1	7												
7										1						3												
8										1						1						1						
9												1				1												
70						1																						
Total			11	6	389	768			255	155	119	175	3		507	226	12	17	1		57	21	4	2			1	1
Mean			57.0	57.7	51.7	54.0			57.6	59.6	53.6	54.9	59.0		58.5	60.4	53.5	54.9	61.0		58.7	60.2	56.8	55.0			60.0	64.0

Continued . .

G-4. Sockeye, 1960 (Continued).

East of 170°E. North of 52°N -July

	3_1		4_1		4_2		5_1		5_2		5_3		6_2		6_3		6_4		7_3		7_4		7_5		8_3		8_4	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
45																												
6					1																							
7											1																	
8					2							1																
9					7	1					2																	
50					9	1						3																
1					5	2					1																	
2					7	5					1				1													
3					6	3					1				1						1							
4					5	4					2				2													
55					1	4			1			2			2	2												
6			1		3	5			1		1	3			1													
7					2	3			5	1	1				7	1					4							
8						1			2		1	1			8	2					1							
9									3	2		2			16	1					1							
60			1						2			1	1		8	2												
1									1						6	2						1						
2										2		1			7	1						1						
3									1							3												
4										2					1	2												
65															1	1												
Total			2		48	29			16	7	11	14	1		61	17					7	2						
Mean			58.0		51.6	54.0			58.3	61.0	52.7	55.3	60.0		58.9	60.5					56.9	61.5						

Continued . . .

G-4. Sockeye, 1960 (Continued).

East of 170°E, North of 52°N—August

	3_1		4_1		4_2		5_1		5_2		5_3		6_2		6_3		6_4		7_3		7_4		7_5		8_3		8_4	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
41																												
2												2																
3																												
4												1																
45																												
6																												
7					2	1					1	5																
8					1	1					5	5																
9						3			1			2																
50						1					1	4																
1						4					1	4																
2						3					1	6																
3												1																
4												1																
55																												
6					1						1				2		1											
Total			[illegible]		4	13			1		10	31			2		1											
Mean					49.5	50.2			49.0		49.6	49.2			56.0		56.0											

Continued

G-4. Sockeye, 1960 (Continued).

West of 170°E—May

	3_1		4_1		4_2		5_1		5_2		5_3		6_2		6_3		6_4		7_3		7_4		7_5		8_3		8_4	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
41																												
2																												
3																												
4																												
45											1																	
6									1		1																	
7											3	1																
8									1	1	6	2						4										
9					3	2			1	1	11	5			1			1										
50					1	4				3	13	15			1			2										
1		1	1			7			10	3	5	25			2	1	3	2				2						
2			1	1		4			17	4	4	39			4	4	1	3				1						
3			5			6			14	2	6	27			16	1	1	2				2						
4			6		1	8	1		35	5	3	25			17	5		3		1	1							
55			9	1	2	5			50	11	3	19			48	9		2			8	3						
6			2			3	1		40	8	3	2			32	10					4	3						
7			3	1			1		20	14	1	2			20	9				1	9	4						
8			2	5	2				13	16	1	1			22	14			1		4	3						
9				2		1			13	27		1	1		12	27			3		2	3						
60			1	4	1		1		10	24			1		6	24					4	11					1	
1			1	3					2	14					1	16						4						
2				1					1	8					4	12												
3										4						5				1		2						
4										1		1			1	1				1								
65									1	1						2												
6															1	1												
7																1												
8																1												
9										1																		
70																1												
Total		1	31	18	10	40	4		229	148	61	165	2		188	144	5	19	4	4	32	38					1	
Mean		51.0	55.1	58.7	53.7	52.9	56.8		55.3	58.1	50.8	52.6	59.5		56.0	59.0	51.6	51.4	58.8	59.5	56.9	57.9					60.0	

Continued

G-4. Sockeye, 1960 (Continued).

West of 170°E—June

	3_1		4_1		4_2		5_1		5_2		5_3		6_2		6_3		6_4		7_3		7_4		7_5		8_3		8_4	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
41						1																						
2										1																		
3					1	2					3	2																
4					3	1			2		2	2																
45					4	1			2	2	19	4					1	2										
6			2		7	3			1	1	46	27			2	1	8	1			1							1
7		1	1		9	6			6		39	43			1	1	4	8										
8			2	1	2	8	1		17	4	36	57			6	2	4	3			1							
9			4	1	3	11			31	8	21	58			17	4	2	8	1		2				1			
50			5			16			56	3	12	68			28	6	3	6			5	1						
1	1		9		2	6	1		65	6	9	37			43	6	1	4			4	2						
2			3			5	1		70	8	3	25	1		40	14	1	4			8	2						
3			3	1		2			72	15	2	7			42	20		1			7	5		1				
4			2	2		1			40	24	2	5	3		55	13		1	4		15	3				1		
5			2	4			2		31	21	1	2	1		41	23		1	3		9	6						
60				1		1	1		20	33		1	2		44	23			2	1	13	8						
1			1	2					6	25	1	1	3		16	17	1		1		5	2						
2				1			1		3	18			1	1	9	16					2	4						
3				1			1		1	15		1	1		5	15					2	3						
4									1	8			1	1	1	4					1	2						
65									2	3				1	1	9				1		2				1		
6															2					1								
7									1	1				1		5				1								
8																1												
9													1	1		1												
70														1							1							
Total	1	1	34	14	31	64	8		427	196	196	340	14	6	353	181	25	39	11	4	76	40		1		1	2	1
Mean	55.0	51.0	54.9	58.6	50.6	53.1	58.3		56.0	59.1	51.5	53.1	60.7	66.2	57.3	59.5	52.0	53.3	58.5	64.5	58.1	59.7		57.0		53.0	61.5	51.0

Continued

G-4. Sockeye, 1960 (Continued).

West of 170°E—July

	3_1		4_1		4_2		5_1		5_2		5_3		6_2		6_3		6_4		7_3		7_4		7_5		8_3		8_4	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
38						1																						
9																												
40						1																						
1												1																
2											1																	
3					2	1						1																
4		1			2	1					4	1																
45					7	2			1	1	8																	
6					15	15					20	12					2											
7		1			18	29					49	27			1		5	1										
8			3	3	17	41			1		95	70			1		3	9										
9			2	1	12	45			6	2	90	114	1		3		5	6				3				1		
50		1	3		13	56			11	1	128	204			4	2	14	17				3						
1			6		14	22			10	5	152	139			8	1	21	14			1							
2			6	2	16	17			9	3	190	134			8	5	23	13			2	2						
3			1	3	14	13			13	8	210	164			7	1	25	19			1	1				1		
4			3	4	6	11			15	8	145	130			4	6	16	19			2	2						
55			1	2	3	12			25	14	97	176			24	5	14	17			7	2						
6			5	5	3	7			29	18	33	119	1		35	10	6	11			8	2						
7		1	7	3		10			44	14	17	109	1		59	19	5	14			30	9						
8			5	1	1	4			71	10	11	60	1		60	10		5			41	5						
9			4		3	1			40	9	5	31		1	55	10	2	2	1	2	32	4						
60			3	2		2	1		21	15	5	13	3		63	19		2	1		30	13						
1					1				18	17	1	1	4		21	10			1		15	12					1	
2				3					8	16	1	5			10	9					8	8						
3									3	7	1	1	1		10	17		2			3	10						
4				2					1	5		1	2		4	16					1	5						
65										9	1		2	2	1	7			1		1	5						
6						1				1		1				4				1		3						
7				1						1						2				1								
8										1				1	1	2			1									
9								1		1						1												
70																				1		2						
1																												
2														1														
Total		4	49	32	147	292	1	1	326	166	1,264	1,514	16	5	379	156	139	153	5	5	182	88				2		1
Mean		49.5	54.4	56.0	49.8	50.2	60.0	69.0	56.8	58.4	51.7	52.9	60.3	65.8	57.8	59.9	52.4	53.2	62.6	64.2	58.5	59.9				51.0		61.0

Continued . .

G-4. Sockeye, 1960 (Continued).

West of 170°E—August

	3_1		4_1		4_2		5_1		5_2		5_3		6_2		6_3		6_4		7_3		7_4		7_5		8_3		8_4	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
41																												
2																												
3					1																							
4																												
45					1						1																	
6												1																
7					2	4					5						1											
8					4	5					6	3																
9					3	5					5	3					1	1										
50					2	3					5	6			1			1										
1					1	4					4	9						1										
2			1		1	5						7						4										
3					1	2				1	1	4						2										
4						2						3						1										
55						1			1			1																
6									1	1	1	3			1			1										
7																		1										
8										2		1			1			1										
9																		1										
60																												
Total			1		16	31			2	4	28	41			3		1	15										
Mean			52.0		48.6	50.2			55.5	56.3	49.1	51.6			54.7		49.0	53.0										

Continued

G-4. Sockeye, 1960 (Continued).

Landbased, South of J-S Treaty Line—May

	3_1		4_1		4_2		5_1		5_2		5_3		6_2		6_3		6_4		7_3		7_4		7_5		8_3		8_4	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
40						1																						
1																												
2																												
3											1																	
4						3					1																	
45						3						3																
6						3						5						1										
7						3					3	6						1										
8						1					3	4																
9											2	2																
50			1									2																
1						2					4	2				1												
2												2																
3												2																
4									1			1			2													
55											1					1												
6											1				1													
7																												
8																												
9																												
60																												
1															1													
Total			1		16				1		16	29			4	2		2										
Mean			50.0		46.0				54.0		49.1	48.4			56.3	53.0		46.5										

Continued . . .

G-4. Sockeye, 1960 (Continued).

Landbased, South of J-S Treaty Line– June

	3_2		4_1		4_2		5_1		5_2		5_3		6_2		6_3		6_4		7_3		7_4		7_5		8_3		8_4	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
41																												
2																												
3																												
4																												
45																												
6											1	1																
7											1	1																
8												1																
9																												
50					1						1																	
1											1																	
2																	2											
3											2						1											
4																		1										
55												1																
6																	1											
7																												
8															1	1												
9															3													
60																												
1																												
2																1												
3																					1							
4																					1							
Total					1						6	4			4	2	4	1			2							
Mean					50.0						50.0	49.0			58.8	60.0	53.3	54.0			63.5							

Note: In July 1960, two male sockeye salmon (each age 6_4) were caught in the region "Landbased, South of J-S Treaty Line". Each was 55.0 cm in length. No separate table has been prepared for these fish.

Continued . . .

G-4. Sockeye, 1960 (Continued).

Landbased, North of J-S Treaty Line July

	3_1		4_1		4_2		5_1		5_2		5_3		6_2		6_3		6_4		7_3		7_4		7_5		8_3		8_4	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
41																												
2																												
3					1																							
4					2																							
45											6	1																
6		1			1						4	2																
7					1						7	6					1	1										
8					1	3					5	4					1											
9						1					4	6			1													
50						1					2	5																
1						1					1	3																
2						1				1	1	2																
3											2	1			1		1											
4											1				1													
55											1	2																
6												1																
7												1						2										
8												2			1	1												
9									1								1											
60												1			2						1							
1																1						1						
2									1						2	1		1										
3															1	1						1						
4									1													1						
65																												
6																1												
Total		1			6	7			3	1	34	37			9	5	4	4			1	3						
Mean		46.0			45.3	49.4			61.7	52.0	48.1	50.4			57.9	62.0	51.8	55.8			60.0	62.7						

Continued

G-4. Sockeye, 1960 (Continued).

Landbased, North of J-S Treaty Line—August

	3_1		4_1		4_2		5_1		5_2		5_3		6_2		6_3		6_4		7_3		7_4		7_5		8_3		8_4	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
41											1																	
2					2						1																	
3						1					1	1						1										
4						1					2	1					1											
45						1					1																	
6			1						1			1										1						
7									1	1		3																
8									2		1	1				1					1	1						
9										1		2									1							
50															1						1							
1															1													
2															1	1						1						
3																												
4															1													
65																												
6															1	2												
7																												
8															1	1												
Total			1		2	3			4	2	7	10			6	5	1	1			3	3						
Mean			54.0		49.0	51.0			56.0	57.5	51.1	54.8			63.5	64.0	51.0	50.0			59.0	58.3						

G-5. Chum, 1957.

East of 170°E—May

	3		4		5		6	
Length	F	M	F	M	F	M	F	M
41		1						
2								
3								
4			1					
45			1	1	1			
6			2	5				
7			6	8		2	2	
8	1	6	11	21	2	1		
9	1	2	30	34	3	2		1
50	1	7	77	59	5	3	3	2
1		2	76	69	15	10	3	2
2		1	76	94	16	10	5	6
3			71	58	32	9	7	4
4			69	81	27	30	12	8
55			66	56	45	28	21	15
6			30	41	51	31	20	9
7			19	23	49	22	25	9
8			17	19	24	20	17	9
9			10	20	30	11	14	7
60			2	7	20	18	10	8
1			4	9	13	13	9	5
2			1	1	3	6	3	
3				1		7	1	5
4				1	1	2		3
65				1		2	1	1
6								
7								
8						1		
Total	3	19	569	609	337	228	153	94
Mean	49.0	49.5	52.6	53.1	55.8	55.9	56.5	56.8

East of 170°E—June

42	1							
3	1							
4		3	1					
45	4	6	1	4	1			
6	6	16	2	6				
7	4	17	22	19				
8	7	19	51	28	3	4		1
9	4	16	58	66	3	4		1
50	5	14	124	143	8	5	3	3
1	6	9	113	136	8	5	1	5
2	3	7	108	114	24	13	4	4
3	2	5	107	113	21	15	2	1
4	3	2	84	84	30	18	10	5
55	4	5	83	95	38	29	9	7
6	3	3	73	46	36	16	8	8
7	3	3	72	45	46	23	6	6
8	2	1	67	48	45	13	11	3
9		2	49	32	40	20	3	9
60			41	31	39	19	9	4
1			21	19	36	10	6	3
2	1		18	9	29	8	4	1
3			12	11	15	5	2	3
4			4	7	13	6		2
65			7	5	9	4	3	
6					4	4		
7			1	1		1		1
8				1				
9								
70								
74				1				
Total	59	128	1,119	1,064	448	222	81	65
Mean	50.5	49.4	53.8	53.3	57.6	56.8	57.2	56.5

Continued . . .

G-5. Chum, 1957 (Continued).

East of 170°E—July

	3		4		5		6	
Length	F	M	F	M	F	M	F	M
41								
2	1							
3		1						
4	1	1						
45	2	2						
6	1	1		1				
7	6	6	9					
8	5	5	4	3				
9	3	5	6	2				
50	2	8	10	3		1	1	
1	1	2	6	7				
2	2	1	9	10				
3	1	1	8	13	1		2	
4	4		5	6	1	2		1
55			3	5	1			1
6	2	2	6	3	1			
7	1	2	5	4		1		
8		2	2	4		1		1
9	3	2	3	5		1		
60			8	2	1	3		
1		1	2	3				
2			2	4			1	
3	1		5					
4			2					
65			1			1		
6								
7				1	1			
Total	36	42	96	76	6	10	4	3
Mean	50.7	50.4	54.0	54.5	57.5	57.7	54.5	55.6

West of 170°E—May

41			1					
2			1					
3	1		1	2	1			
4			2	1				
45		1	5	3	2	2		
6	2	4	11	4				
7	2	3	9	13		1		
8	3	6	20	19	3	2	2	1
9		3	55	30	4	4	3	1
50	3	6	135	87	16	11	6	4
1	1	1	140	122	23	10	7	6
2	2	1	149	129	28	18	13	6
3			136	105	49	33	11	11
4		1	113	98	48	32	16	12
55	1	1	73	108	62	33	38	19
6	1		34	48	79	27	46	20
7			21	30	39	29	27	17
8			16	13	33	21	20	17
9			5	14	34	11	20	9
60			5	6	22	15	18	10
1			2	1	6	10	7	5
2				1	3	8	3	7
3					2	6	1	4
4					1	1	1	
65								1
6							1	1
7								1
Total	16	27	934	834	455	269	240	152
Mean	49.3	48.8	52.2	52.9	55.2	55.3	56.1	56.3

Continued . . .

G-5. Chum, 1957 (Continued).

West of 170°E—June

	3		4		5		6	
Length	F	M	F	M	F	M	F	M
41								
2								
3	1	1		1	1			
4		1		1	1			
45	1	5	6	2				
6	1	4	4	9			1	
7	2	7	15	11	1			
8	3	12	56	42	5	2		1
9	13	14	78	69	6	2	3	1
50	17	26	125	125	14	7	4	4
1	14	21	163	129	22	13	4	2
2	5	7	150	131	33	16	5	3
3	8	15	164	128	43	23	13	5
4	7	8	159	121	49	28	18	7
55	2	6	140	117	51	34	29	11
6	1	1	90	47	39	23	21	11
7	1	2	60	42	51	29	15	15
8		1	41	42	50	24	15	15
9		1	19	21	24	16	10	8
60			15	16	29	16	11	13
1			4	9	19	12	10	7
2				3	9	5	4	3
3				3	1	2	2	3
4			2		3	3	1	2
65				1		2		1
6								
7								
8								
9								
70						1		
Total	76	132	1,291	1,070	451	258	166	112
Mean	50.8	50.5	52.8	52.8	55.6	55.9	56.1	57.1

West of 170°E—July

41	1							
2	1							
3		2	1					
4	4	4	3	1				
45	7	11	2	1		1		
6	9	24	8	4				
7	22	27	16	23		1		
8	17	40	50	42	1	1	1	
9	24	53	82	76		3		
50	38	48	157	170	8	3	2	2
1	32	31	150	163	11	5	3	1
2	34	38	138	154	14	11	6	3
3	12	30	146	157	11	17	5	5
4	28	29	127	157	18	16	9	7
55	8	21	178	117	44	25	11	9
6	8	11	135	92	37	27	6	3
7	11	6	131	65	51	18	20	11
8	8	3	98	46	35	15	13	7
9	3	1	55	33	29	9	11	2
60		2	57	31	39	13	7	5
1			39	22	9	9	7	1
2	3		9	12	19	8	5	2
3			14	3	9	3	8	3
4			4	5	8	3	2	
65	1		5	2	4	1	2	5
6			1	2	3	2	1	
7		1		1		2	1	
8				2			1	
9	1		1			1		
Total	272	382	1,607	1,381	350	194	121	66
Mean	51.2	50.5	53.9	53.2	57.3	56.4	57.5	57.0

Continued

G-5. Chum, 1957 (Continued).

Okhotsk Sea—June

	3		4		5		6	
Length	F	M	F	M	F	M	F	M
41								
2								
3								
4								
45								
6		1				1		
7		2						
8	1	2	2	2				
9		3	6	6			1	
50	1	2	15	11				
1	1	3	29	21	4	2	1	
2	2	2	41	33	2	3	1	1
3	3	1	49	42	9	4	5	
4			85	48	7	4	3	
55	1	2	54	48	16	2	8	
6	1	1	25	36	11	8	7	4
7			15	27	10	5	8	2
8			12	12	21	3	11	
9		1	1	3	2	3	10	
60			1	2	5	1	3	5
1					2		2	
2							1	1
3							2	
4			1					
65								1
6							1	
Total	10	20	336	291	89	36	64	14
Mean	50.9	52.3	53.7	53.7	56.1	55.2	59.0	58.

Okhotsk Sea—July

41								
2								
3								
4								
45								
6		1						
7		1						
8	3	2	1	1				
9	4	3		3				
50	7	6	12	14	1	1		
1	11	19	22	12				
2	13	17	30	17	1			
3	9	11	55	25	3		2	
4	5	10	71	45	6	3	2	
55	3	7	83	40	9	3	1	1
6	3	7	87	39	7	3	3	
7	1	3	47	16	8	4	5	1
8	3	2	24	15	14	1	6	2
9		1	23	8	4	1	7	
60		2	16	7	5		4	
1			7	7	3	3	2	1
2			4	2			4	
3			1	3			1	
4			1	1			1	1
65								
6								
7						1		
Total	62	92	484	255	61	20	38	6
Mean	52.2	52.8	55.2	54.9	57.0	57.0	58.3	58

Continued

G-5. Chum, 1957 (Continued).

Landbased, South of J-S Treaty Line—June

	3		4		5		6	
Length	F	M	F	M	F	M	F	M
41								
2								
3								
4								
45								
6				1		1		
7				1				
8			2	1	1			
9	2		1		1			
50			2	2				
1	1		1	5		1		
2	1		6	3				
3			4	4				
4		1	4	3	3			
55			2	6	1	3		
6			3	6	3	2		
7			1	2	1	3		
8			3	3	5	2		
9			2	3	7	3		
60			1	5	5	3		
1				1	2	2		
2				1	2	2		
3				1		2		
4				1	1	1		
65								
6								
7				1		1		
Total	4	1	32	46	32	26		
Mean	50.3	54.0	53.8	54.7	57.9	58.5		

Landbased, South of J-S Treaty Line—July

41								
2								
3								
4								
45		1						
6								
7		1		1				
8	1	2	1	1				
9	2	1						
50	2	1	2	2				
1	1	3	5					
2		2	5	5	1	1		
3	2	3	11	7	1			
4	3	5	13	14		1		
55	3	3	14	14	2	1		
6			7	7	6	1		
7			12	11	6	3		
8	1		10	8	14	3		
9	1		5	6	14	5		
60			3	6	6	7		
1			3	4	9	5		
2				4	7	5		
3				1	2			
4			1		4			
65				1				
6								
7						1		
Total	16	22	92	92	72	33		
Mean	52.9	51.7	55.4	56.2	59.1	59.4		

Continued

G-5. Chum, 1957 (Continued).

Landbased, South of J-S Treaty Line—August

	3		4		5		6	
Length	F	M	F	M	F	M	F	M
41								
2								
3								
4								
45								
6								
7								
8								
9								
50	1	1						
1								
2		1						
3	2	3						
4	2		2	1				
55			2		1			
6			1	1				
7		1	2	1		1		
8			1					
9			2		1			
60								
1								
2					1			
3								
4								
65						1		
Total	5	6	10	3	3	2		
Mean	52.8	53.0	56.4	55.7	58.7	61.0		

Landbased, North of J-S Treaty Line—June

41								
2								
3								
4								
45								
6								
7				1				
8		1						
9	1							
50	2		1					
1			1					
2	1	1	1					
3		3	1					
4		2	1					
55	2	1	2					
6				2	2			
7			2	2	1			
8					1			
9					2	1		
60			1	1	2			
Total	6	8	10	6	8	1		
Mean	51.8	52.8	54.4	55.5	58.1	59.0		

Continued

G-5. Chum, 1957 (Continued).

Landbased, North of J-S Treaty Line—July

	3		4		5		6	
Length	F	M	F	M	F	M	F	M
41								
2								
3								
4								
45		1						
6			1					
7	4	3	1					
8	4	4	1					
9	3	5	2					
50	6	7	4	1	1			
1	3	8	3	1				
2	1	6	3	1				
3	2	3	13	6				
4		1	9	6		1		
55		1	16	9	2	1		
6		1	21	10	3			
7	2	1	10	9		1		
8			8	3	3			
9			5	2	2			
60			1	4	4			
1			3		4	2		
2			1	1	3			
3			1			1		
4				1				
65					1	2		
Total	25	41	103	54	23	8		
Mean	50.1	50.6	55.1	55.9	58.9	60.1		

Landbased, North of J-S Treaty Line—August

41								
2								
3								
4								
45								
6	1							
7	2							
8	5	1						
9	2	1		1				
50	1	1		1				
1	1	1						
2	5	2	3					
3	1	2	2	1				
4	2	1		1				
55		1	3	2				
6		1	3	1				
7			1	3	1			
8				1				
9			1					
60	1		3					
1			2	1				
2			1					
3			1					
4			2		1			
65								
6								
7			1	1				
8				1		1		
Total	21	11	23	14	2	1		
Mean	50.5	52.1	58.0	56.9	60.5	68.0		

G-6. Chum, 1958.

East of 170°E—May

	3		4		5		6		7	
Length	F	M	F	M	F	M	F	M	F	M
41										
2										
3										
4										
45					1					
6				1						
7			2							
8			3	4						
9			3	3	1	2				
50			17	13	2	2				
1			15	19	7	4				
2		1	34	18	7	7				
3			40	42	20	6	1			
4			53	44	22	14				
55			67	55	41	17				
6			49	43	41	21	1			
7			43	43	39	18	1	1		
8			33	36	41	19	1	1	1	
9			21	14	39	19	1	1		
60			9	22	13	6	7	1		
1			6	11	8	12		2		
2			2	2	6	9				1
3						8				
4				1	2	4				
65						2				
6								1		
7				1						
8						1				
Total		1	397	372	290	171	12	7	1	1
Mean		52.0	54.9	55.3	56.5	57.4	58.6	60.3	58.0	62.0

East of 170°E—June

41										
2										
3										
4										
45		1		1						
6	1	3	2	1						
7		3	4	4						
8	2	10	10	5						
9		11	23	25	6	1				
50	5	15	58	46	8	5				
1	1	3	64	55	15	5				
2	2	6	79	58	12	12				
3		3	96	69	30	13				
4		3	90	49	15	18				
55	1	1	114	61	34	24				
6			67	54	36	16		1		
7			60	37	27	11	2	1		
8			31	39	18	11	1	1		
9			16	23	26	9	1			
60			4	11	15	9	1	1		
1			3	10	10	4				
2			2	7	4	8	1	1		
3				2		3				
4							1			
65										
6										
7										
8				1						
Total	12	59	724	557	256	149	7	5		
Mean	50.2	49.7	53.7	54.0	55.6	55.8	59.6	58.6		

Continued . .

G-6. Chum, 1958 (Continued).

East of 170°E—August

	3		4		5		6		7	
Length	F	M	F	M	F	M	F	M	F	M
41										
2										
3										
4										
45	1			1						
6	1	2								
7	5	3								
8	3	3		2						
9	2	6	1							
50		8	4	2						
1	3	4	4	1						
2	1	3	2	8						
3	2	1	3	4						
4	3	5	4	7	1					
55	4	3	4	7						
6	3	5	3	7		1				
7		5	1	7	1	1				
8		2	2	5		2				
9			2							
60	2		2		1					
1			1							
2			4							
3			2	2						
4			1							
65										
6										
7			1							
Total	30	50	41	53	3	4				
Mean	51.6	52.0	56.0	54.5	57.0	57.3				

West of 170°E—May

41										
2										
3										
4										
45										
6			1							
7		1	5	4						
8			7	4						
9		2	25	13		1				
50		1	62	37	6	6	1			
1			65	59	15	7	1			
2		1	122	74	43	18	2			
3	1		179	110	62	32	1	1		
4			168	154	96	56	3			1
55			181	148	135	68	1	1		
6			122	128	86	68	4	1		
7			77	94	100	46	2			
8			52	86	82	51	2	2		
9			18	43	67	49	6	2	1	1
60			14	30	42	35	1	1	2	
1			4	14	13	15	3			
2			4	4	11	12	2	1		
3				3	2	6		1		
4				1	2	7		1		
65			1		2	6	1			
6					2					
7				1						
8			1							
Total	1	5	1,108	1,007	766	483	30	11	3	
Mean	53.0	49.4	54.0	54.9	56.0	56.6	57.2	58.8	59.7	60

Continued

G-6. Chum, 1958 (Continued).

West of 170°E—June

	3		4		5		6		7	
Length	F	M	F	M	F	M	F	M	F	M
41	1			1						
2										
3										
4		4								
45	1	11	2							
6	7	19	9	3						
7	15	44	22	10						
8	22	55	70	35						
9	18	66	110	65	6	1				
50	27	83	281	158	18	6				
1	17	53	371	206	29	13				
2	18	47	433	287	55	29				
3	8	23	458	294	77	37				
4	1	15	460	311	105	52	1			
55		11	418	240	122	60				
6	1		351	233	114	57	4	3		
7	2		241	158	119	48	3			
8	1		172	136	89	36	5		1	
9		1	90	85	65	24	4	1		
60			48	49	39	30	1			
1			17	35	26	18	6			
2			12	14	16	12	1			
3			2	7	7	9	1	1		
4			2	6	2	5			1	
65			1	2	2	1				
6				1	2					
7						2				
8						1				
Total	139	432	3,570	2,336	893	441	26	5	2	
Mean	49.7	49.7	53.7	54.1	55.9	56.3	58.8	58.0	61.0	

West of 170°E—July

41	2	1								
2	1	1								
3	2	6								
4	10	9	2	1						
45	23	32	4							
6	65	78	5	5						
7	125	148	25	12						
8	172	254	65	38						
9	182	301	111	56	1	1				
50	213	315	216	139	5	3				
1	179	309	258	170	5	4				
2	123	284	332	279	16	12				
3	114	235	377	247	21	12				
4	61	154	336	235	39	18				
55	26	129	325	238	49	22	1			
6	29	75	291	181	51	22		2		
7	15	36	225	156	53	31				
8	5	17	197	111	45	24	1			
9		9	137	78	42	14		1		
60	3	3	105	76	29	13		1		
1	1	1	54	34	18	7				
2			41	33	12	4		1		
3			17	23	12	2				
4			14	9	1	1				
65		1	6	4	1	1				
6		1	5	1	2	6				
7			4	4						
8			2	1						
9			1	1		2				
70										
1						1				
Total	1,351	2,399	3,155	2,132	402	200	2	5		
Mean	50.1	50.8	54.3	54.4	56.9	56.9	56.5	58.6		

Continued . . .

G-6. Chum, 1958 (Continued).

West of 170°E—August

	3		4		5		6		7	
Length	F	M	F	M	F	M	F	M	F	M
41										
2										
3		1								
4	5	4								
45	15	14	3							
6	26	34		2						
7	69	65	5	4						
8	66	89	16	6						
9	59	100	22	21						
50	48	87	40	25						
1	52	74	65	37						
2	24	64	59	65		1				
3	29	49	65	62	3					
4	25	42	54	50						
55	26	33	48	64	2	2				
6	8	20	35	54	14	2		1		
7	9	15	21	33	6	6				
8	3	9	27	27	6	5				
9	1	8	22	21	11	1				
60	2	5	23	8	4	7				
1			15	9		4			1	
2		1	20	7		3	1	1		
3		1	13	8	4	1				
4			9	1	1					
65		1	8	5	1					
6			5	3	1					
7			2	2						
8			1	1						
9			2							
70				1						
1										
2										
3					1					
4				1						
Total	467	716	580	517	54	32	1	2	1	
Mean	49.9	50.6	54.7	54.6	56.4	56.7	62.0	59.0	61.0	

Okhotsk Sea—June

41										
2			1							
3										
4			1							
45			2							
6		3			1					
7			2	1						
8	1	4								
9		8	5	2	2					
50		4	18	7	2	2				
1	2	7	25	15	5	1				
2	1	19	41	29	4	10				
3	1	11	53	29	12	8				
4		11	29	38	18	14				
55	2	15	38	30	22	13				
6		6	15	22	26	13				
7		1	10	13	8	5	1			
8			1	6	3	7				
9			1	1	3					
60		1	1							
1			1							
2						1				
Total	7	90	244	193	106	74	1			
Mean	52.1	52.5	53.0	53.8	54.6	54.7	57.0			

Continued

G-6 Chum, 1958 (Continued).

Okhotsk Sea—July

	3		4		5		6		7	
Length	F	M	F	M	F	M	F	M	F	M
41										
2										
3										
4			1							
45		2		1						
6	1	5	1							
7	1	2		2						
8	6	5	4							
9	21	26	9	2						
50	19	37	13	10						
1	13	34	28	9	1					
2	21	41	23	16	5					
3	7	29	39	17	1					
4	6	25	41	28	2					
55	6	13	47	18	4	1				
6	3	6	25	21	8					
7	2	6	15	10	8					
8	1	4	11	12	3	1				
9			12	11	2	4				
60		1	8	3	4					
1			6	4	3					
2			3	2	1	1				
3				1						
4				1		1				
65				1	1					
6										
7			1							
Total	107	236	287	169	43	8				
Mean	51.2	51.8	54.2	54.8	56.7	59.4				

Okhotsk Sea—August

41										
2										
3										
4										
45										
6		2								
7	3	1								
8	3	7								
9	8	4	1							
50	5	9		2						
1	15	8	3	1						
2	4	15	2							
3	7	11	6	2						
4	4	10	7	4						
55	1	6	3	7						
6	1	10	4	8	1					
7		3	6	2						
8		1	5	2						
9	1	1	4	2						
60			11	2	1					
1			7	1						
2		2	8	2	2					
3			4	1						
4			3	2						
65					1					
6			1							
Total	52	90	75	38	5					
Mean	51.1	52.6	58.0	56.6	61.0					

Continued . . .

G-6. Chum, 1958 (Continued).

Landbased, South of J-S Treaty Line—May

	3		4		5		6		7	
Length	F	M	F	M	F	M	F	M	F	M
41										
2										
3										
4										
45										
6		1								
7		1								
8		1	1	1						
9		6		1		1				
50	2	2	8	4						
1	3	7	10	7	1					
2	3	4	10	8						
3	2	4	22	16	2	1				
4	2		24	25	2	1				
55		1	22	25	1	5				
6			23	30	4	1		1		
7			17	25	2	4				
8			13	22	5	5				
9			7	8	3	6				
60			7	10	1	5				
1			2	3	1	4				
2			1	1	2	1				
3			1	1		1				
4				1		1				
65								1		
Total	12	27	168	188	24	36		2		
Mean	51.9	50.6	55.0	55.7	57.1	58.1		60.5		

Landbased, South of J-S Treaty Line—June

41										
2										
3		1								
4										
45		1		1						
6	2	4								
7	3			1						
8		5	3	2						
9	2	19	3	4						
50	7	17	13	9						
1	5	16	14	15		1				
2	7	18	33	17		2				
3	6	11	32	33		1				
4	3	8	34	38	4	3				
55	4	5	47	44	4	4				
6	7	2	63	44	2	1				
7	1	2	50	41	7	1				
8	1	2	39	37	6	4				
9		2	13	28	2	1				
60			9	14	7	1				
1			3	11	1					
2			3	7	1	1				
3			1	6			1			
4						2				
65								1		
6			1							
7							1			
8			1							
9				1						
Total	48	113	362	353	34	22	2	1		
Mean	52.2	51.3	55.3	55.8	57.5	56.6	65.0	65.0		

Continued.

G-6. Chum, 1958 (Continued).

Landbased, South of J-S Treaty Line—July

	3		4		5		6		7	
Length	F	M	F	M	F	M	F	M	F	M
41										
2										
3										
4										
45										
6										
7	1	3								
8	2	2		1						
9	2	4	1							
50		3		1						
1	3	1								
2	2	4	2	3						
3		3	3							
4	1	3	1	3						
55			4	1						
6	1		1	1						
7		1	1							
8		1		1	1	1				
9			1	1						
60			3	1						
1										
2			1	1						
Total	12	25	18	14	1	1				
Mean	50.7	51.1	55.6	54.7	58.0	58.0				

Landbased, North of J-S Treaty Line—May

41										
2										
3										
4										
45										
6		1								
7				2						
8			4	2						
9			4	2		1				
50			4	6	2	2				
1			4	9	1					
2			11	7	2	1				
3			5	10	2	1				
4			4	7		2				
55			4	4	2	2				
6				4		1				
7			1	3		1				
8			2	1	1	2	1			
9				1						
60				1		1				
Total		1	43	59	10	14	1			
Mean		46.0	52.1	52.7	52.9	54.4	58.0			

Continued . . .

G-6. Chum, 1958 (Continued).

Landbased, North of J-S Treaty Line—June

	3		4		5		6		7	
Length	F	M	F	M	F	M	F	M	F	M
41										
2										
3	1	1								
4		1								
45		1								
6	8	7								
7	9	9	1	2						
8	17	17	2	4						
9	19	14	13	5						
50	16	21	16	11						
1	6	12	19	12						
2	3	9	30	7						
3	2	5	26	8		2				
4		4	26	21	3					
55	1	3	29	26	6	2				
6	1	1	18	18	6	4				
7	1	1	11	10	3					
8			7	9	4	1				
9		1	5	10	2	1				
60			1	5		2				
1					1	1				
2					2	1				
3				1	1					
Total	84	107	204	149	28	14				
Mean	49.0	49.8	53.3	54.3	57.0	57.1				

Landbased, North of J-S Treaty Line—July

41										
2										
3										
4	3	4								
45	7	9		1						
6	14	19								
7	25	28	2	2						
8	26	39	6	4						
9	20	33	12	6						
50	20	37	19	14		1				
1	17	16	27	13						
2	5	17	17	12		1				
3	2	14	21	18						
4	3	4	16	16	2					
55		4	14	19		1				
6		4	11	11	2					
7		1	14	8	2	2				
8		1	8	5	2	2				
9			12	5	2	1				
60		1	6	2	3	1	1			
1			3	2	1					
2			5	2				1		
3			2	2	1					
4			1	2						
65				3						
6										
7				1						
8						1				
9					1					
Total	142	231	196	148	16	10	1	1		
Mean	48.5	49.3	53.9	54.2	58.8	57.4	60.0	62.0		

Continued.

G-6. Chum, 1958 (Continued).

Landbased, North of J-S Treaty Line—August

	3		4		5		6		7	
Length	F	M	F	M	F	M	F	M	F	M
41										
2		1								
3	1									
4	2	6								
45	1	2								
6	4	8	1							
7	9	9		1						
8	13	10	3							
9	3	13	2	1						
50	6	6	7	1						
1	3	5	4	4						
2	4	4	4	3						
3	2	1	6	8						
4	2	3	7	4						
55			4	7						
6			5	5						
7			4	3						
8			12	4		1				
9		1	8		1					
60		1	9	7	1	1				
1			12	3						
2			12	1	1	1				
3			7	2	2					
4			5	1	1	1				
65			2	3						
6			1							
7										
8			1	3						
9			1							
70										
1				2						
Total	50	70	117	63	6	4				
Mean	48.6	48.6	57.7	57.3	61.8	61.0				

G-7. Chum, 1959.

East of 170°E—May

	3		4		5		6	
Length	F	M	F	M	F	M	F	M
41								
2								
3								
4								
45								
6								
7			2	3				
8			5					
9			16	12				
50			24	17				
1			34	15	1	2		
2		2	52	29	3			
3			50	27	4	2		
4			37	31		1		
55			27	25	3	2		
6			15	16	3	2		
7			6	15	2	1		
8			5	7	1	1		
9				4	1	2		
60			2	4	3	2		
1						2		
2								
3					1			
Total		2	275	206	22	17		
Mean		52.0	52.7	53.5	55.7	56.4		

East of 170°E—June

41								
2			2					
3								
4								
45		1	6					
6	1	4	7	3				
7	4	9	23	8				
8	4	6	44	24				
9	4	10	100	49		1		
50	2	9	132	106	1	2		
1		8	167	110	2	2		
2			180	138	4	1		
3	1	1	215	157	4	2		
4		3	201	121	6	2		
55	2		229	119	8	3		
6			166	113	9	4		
7			154	89	6	1		
8			110	64	14	4		
9			75	57	9	4		
60			36	46	7	3		
1			10	21	6	4		
2			11	17	3	4		
3			6	12	6	1		
4				5		1		
65			1	6		1		
6				2				
7				1		1		
8				1				
Total	18	51	1,875	1,269	85	41		
Mean	49.2	49.1	53.8	54.3	57.4	57.6		

Continued

G-7. Chum, 1959 (Continued).

East of 170°E—July

	3		4		5		6	
Length	F	M	F	M	F	M	F	M
40	1		1					
1	3							
2	1		1					
3	2	1	1					
4	5	4	1					
45	7	16	3	5				
6	9	18	5	4				
7	13	23	20	5		1		
8	13	20	27	29				
9	9	24	64	33	2	1		
50	12	25	99	85				
1	9	6	94	77	1	1		
2	4	12	90	116				
3	8	8	127	101				
4	5	7	109	98		1		
55	5	9	151	121				
6	2	3	125	93	1	3		
7	3	3	142	67	4	3		
8		2	101	60	4	1		
9		2	81	36	3			
60			87	36	2	1		
1		1	41	17	1	4		
2			15	11	1			
3			17	9	6	1		
4			2	5	4	2		
65			4	3				
6				3	1	1		
7					1			
Total	111	184	1,408	1,014	31	20		
Mean	48.9	49.4	54.8	54.1	59.7	57.9		

West of 170°E—May

41								
2								
3								
4								
45								
6		1	1	2		1		
7	1		8	5				
8	1	4	35	12	1	2		
9		1	72	34		1		
50	1		188	110	4	5		
1		1	192	84	7	2		
2		2	232	129	9	4		
3			195	140	12	9		
4			166	135	13	3		
55			135	113	16	12		
6			64	84	19	9		
7			26	55	13	2		
8			27	43	14	10		
9			7	18	9	11	1	
60		1	4	12	5	10		
1			3	8	2			
2				4	1		1	
3				2	1			
4						2		
65						2		
Total	3	10	1,355	990	126	85	2	
Mean	48.3	50.2	52.5	53.5	55.4	55.9	60.5	

Continued . . .

G-7. Chum, 1959 (Continued).

West of 170°E—June

	3		4		5		6	
Length	F	M	F	M	F	M	F	M
40				2				
1	1							
2								
3			3					
4	3	1		3				
45	2	4	2	3				
6	8	9	7	6				
7	14	21	30	18				
8	6	35	77	70				
9	11	29	149	94	1			
50	10	33	372	213	2	4		
1	5	18	340	226	4	1		
2	4	14	482	244	8	3		
3	2	11	483	281	12	3	1	
4		3	370	267	15	5		
55			367	240	15	12		
6			295	186	17	15		1
7		1	187	141	21	9	1	
8			130	130	15	16	1	
9			69	80	16	8		
60			54	59	12	13		
1			22	31	10	5		
2			6	18	7	3	1	
3			6	5	2	4	1	
4			2	6		2		
65				3		2	1	
6				1	1			
7								
8						1		
9					1	1		
Total	66	179	3,453	2,326	159	107	6	1
Mean	48.3	49.3	53.3	53.7	56.8	57.6	59.7	56.0

West of 170°E—July

41								
2			1	1				
3	1							
4	1	2		2				
45	2	7	2					
6	6	16	2	2				
7	13	31	6	3				
8	26	36	19	11				
9	27	30	36	19				
50	32	39	87	70				
1	15	29	101	88				
2	4	13	116	96				
3	7	16	160	114				
4	3	11	163	120	3	2		
55	2	5	189	111	4	1		
6	2	4	180	97	3	2	1	
7	2	3	159	74	8	3		
8	2	1	175	71	5	1		
9	1		124	56	3			
60	1	1	102	49	4	1		
1			67	36	6	3		
2			32	25	2	1		
3			15	23	4			
4			5	12	2			
65			2	5	1	2		
6				2	1			
7				2				
8								
9								
70				1	1			
Total	147	244	1,743	1,090	47	16	1	
Mean	49.7	49.7	55.6	55.1	59.2	58.7	56.0	

Continued

G-7. Chum, 1959 (Continued).

Landbased, South of J-S Treaty Line -May

	3		4		5		6	
Length	F	M	F	M	F	M	F	M
41								
2								
3								
4				1				
45		1						
6								
7			9	1				
8	3	1	9	4				
9	1		13	8				
50	1	1	32	22				
1		1	43	40	1	2		
2			57	41	2	3		
3			37	40	3	4		
4	1		34	27	3	6		
55			17	38	12	6		
6			12	37	6	9		
7			6	20	5	5		
8			6	12	4	5		
9			6	12	2	6		
60				2	2	6		1
1			1	2	4	1		
2			1	3	1	1		
3				1				
4				1				
65								
6					2	1		
Total	6	4	283	312	47	55		1
Mean	49.5	48.5	52.4	53.8	56.7	56.5		60.0

Landbased, South of J-S Treaty Line—June

41								
2								
3								
4		1		1				
45		1						
6			1					
7	3	3	6	3				
8	4	3	14	6				
9	4	3	14	10				
50	3	4	25	18				
1	2	2	48	21				
2	4	11	49	27	2	1		
3	3	4	63	28	1			
4	5	2	72	35	3	2		
55	2	3	70	47	7	2		
6	2	1	59	40	8	5		
7	1	3	49	51	5	3		
8			34	48	5	6		
9			14	36	5	7		
60			11	15	3	5		
1			2	4	1	10	1	
2				2	2	1		
3			1	3	1	1		
4				1	2	2		
Total	33	41	532	396	45	45	1	
Mean	51.4	51.4	54.0	55.2	57.3	58.8	61.0	

Continued . .

G-7. Chum, 1959 (Continued).

Landbased, North of J-S Treaty Line—June

	3		4		5		6	
Length	F	M	F	M	F	M	F	M
41								
2								
3								
4								
45	1			1				
6			1					
7		2						
8		2						
9	2		5	2				
50	1	1	8	3				
1			9	4	1			
2	1		12	9				
3		2	24	12	1			
4		1	22	19	1			
55		2	23	16				
6	1		19	19	3	1		
7			12	17		3		
8			13	10	1	1		
9			1	8	1	1		
60			3	4				
1				4				
2								
3				1				
4						1		
Total	6	10	152	129	8	7		
Mean	50.2	51.0	54.2	55.3	55.4	58.3		

Landbased, North of J-S Treaty Line—July

41								
2								
3								
4	1	2						
45	5	2						
6	6	8						
7	18	20		2				
8	24	32	1	3				
9	36	50	16	7				
50	27	40	18	14				
1	18	33	34	19				
2	14	23	39	30				
3	2	19	49	28				
4	7	19	50	34	1			
55	2	10	45	34	3			
6	1	6	49	40	4	1		
7	1	3	44	38	4			
8	2	2	27	28	2	1		
9			25	20	3	2		
60			17	17	4			
1			12	6	5	1		
2			3	4	2			
3			1	4	1	2		
4			1	5	1	1		
65				3	1			
6				1	1	1		
Total	164	269	431	337	32	9		
Mean	49.6	50.4	54.8	55.4	59.1	61.0		

Continued

G-7. Chum, 1959 (Continued).

Landbased, North of J-S Treaty Line—August

	3		4		5		6	
Length	F	M	F	M	F	M	F	M
41								
2								
3								
4	1	1						
45	2	1						
6	4	3						
7	3	4						
8	8	7	1					
9	4	11						
50	8	9	3					
1	5	12	3	2				
2	4	11	13	5				
3	6	10	7	7				
4	6	6	10	14				
55	1	4	7	15	1	1		
6	1	3	7	12				
7	1		4	7	1	1		
8	1	2	9	5				
9	1	1	13	7		1		
60			4	3				
1			6	2	1			
2				3	1			
3			1	1				
4				1	3			
65								
6				1	1			
7			1		1	1		
8								
9								
70				1				
Total	56	85	89	86	9	4		
Mean	50.5	51.1	55.8	56.3	62.2	59.5		

G-8. Chum, 1960.

East of 170°E, South of 52°N—May

	3		4		5		6		7	
Length	F	M	F	M	F	M	F	M	F	M
41										
2										
3										
4										
45										
6										
7			1							
8			2							
9				2						
50			7	5	1	1				
1			5	6	5	1				
2			13	2	4	1				
3			11	7	6	2				
4			13	12	7	5				
55			10	14	9	1				
6			1	7	8	6				
7				5	7	5				
8			6	3	4	6				
9			1	4	3	5				
60					3	2				
1						2				
2						2				
3										
4										
65			1							
Total			71	67	57	39				
Mean			53.3	54.2	55.1	56.8				

East of 170°E, South of 52°N—June

41										
2										
3										
4										
45										
6										
7		2		5	1					
8		1	3	4		1				
9			9	27	2	1				
50			34	31	8	1				
1		2	46	36	8	2				
2			41	44	15	4				
3			36	49	31	7				
4		1	49	50	58	9				
55			70	39	44	17				
6			46	38	40	18	2			
7			22	28	43	19				
8			19	22	31	18				
9			6	13	26	15				
60			1	3	19	13				
1				5	11	8	1			
2				3	10	3				
3				1	1	3				
4					2	1				
65					2	6				
72						1				
Total		6	382	398	352	147	3			
Mean		49.7	53.7	53.7	56.0	57.4	57.7			

Continued

G-8. Chum, 1960 (Continued).

East of 170°E, South of 52°N—July

	3		4		5		6		7	
Length	F	M	F	M	F	M	F	M	F	M
41										
2										
3	1									
4	1	2		1						
45	10	9	1	2						
6	16	9	2	2						
7	14	23	7	3						
8	11	21	14	8						
9	17	23	24	16						
50	14	21	37	29	1					
1	6	13	29	30	2	1				
2	4	10	33	38	2					
3	5	12	31	34	2	1				
4	2	7	21	29	1	2				
55	3	2	29	33	2	2				
6	2		23	22	2	1				
7	1	3	36	24	2	1				
8			19	16	2	3				
9			19	12	5	3				
60	1		15	10	2	4				
1			8	7	4	2	1			
2			6	7		2				
3			1	2	3	4				
4			2	1		1				
65				1						
6			1	2						
7			1	1						
Total	108	155	359	330	30	27	1			
Mean	48.8	49.4	53.4	53.7	53.8	58.8	61.0			

East of 170°E, South of 52°N—August

41										
2										
3										
4										
45										
6										
7										
8										
9			2							
50		2	2	1					1	
1										
2			2	1						
3			1	4						
4			3	1						
55			2	1						
6			1			2				
7				3						
Total		2	13	11		2			1	
Mean		50.0	52.5	54.0		56.0			51.0	

Continued

G-8. Chum, 1960 (Continued).

East of 170°E, North of 52°N—May

	3		4		5		6		7	
Length	F	M	F	M	F	M	F	M	F	M
41										
2										
3										
4										
45										
6										
7										
8										
9										
50										
1										
2			1							
3										
4										
55			1		1	2				
6					1					
7					2					
8				1	4	1				
9					3	2				
60										
1					2					
2						3				
3						1				
4										
65										
6						1				
Total			2	1	13	10				
Mean			53.5	58.0	58.2	60.1				

East of 170°E, North of 52°N—June

41										
2										
3										
4										
45										
6				1						
7			2	3						
8	2	2	10	10						
9		1	31	24						
50			67	65	8	7				
1	1		58	117	8	10				
2		1	96	142	23	27				
3	1		101	158	43	26				
4		1	94	96	44	28				
55		1	98	105	60	44				
6			81	63	65	46				
7			72	51	76	39				
8			59	39	68	39				
9			27	23	55	34	1			
60			20	24	46	27				
1			13	12	30	9				
2			4	4	20	12				
3			1	2	16	9				
4				2	3	6				
65				1	4	3				
6			1		1	2				
7					1	1				
8					1	1				
9				1						
Total	4	6	835	943	572	370	1			
Mean	50.0	51.0	54.2	53.7	57.0	56.7	59.0			

Continued.

G-8. Chum, 1960 (Continued).

East of 170°E, North of 52°N—July

	3		4		5		6		7	
Length	F	M	F	M	F	M	F	M	F	M
41										
2										
3										
4										
45										
6										
7										
8		1	4							
9			7	2						
50			14	9						
1			17	6						
2			12	9	4					
3	1		14	13						
4	1		8	14	4	2				
55			9	12	6	3				
6			13	6	2	2				
7			8	4	3	2				
8		1	7	1	3	1				
9			3	1	3					
60			2	2	1	1				
1					1	1				
2				1						
3				1		1				
4						1				
65					1	1				
Total	2	2	118	81	28	15				
Mean	53.5	53.0	53.2	53.7	56.2	58.0				

East of 170°E, North of 52°N—August

41										
2										
3										
4										
45										
6										
7										
8										
9				1						
50				1						
1				1						
2										
3				2	1					
4				1						
55										
6			1							
7			1							
8				1						
9			2							
60										
1				1						
2				1						
Total			4	9	1					
Mean			57.8	54.6	53.0					

Continued . . .

G-8. Chum, 1960 (Continued).

West of 170°E—May

	3		4		5		6		7	
Length	F	M	F	M	F	M	F	M	F	M
41										
2										
3										
4			1							
45										
6										
7		1	1	1						
8			10	7	1					
9			21	27	2	1				
50		1	58	29	9	4				
1			60	32	15	6				
2			78	62	25	12				
3			83	50	30	14				
4			67	36	44	16				
55			36	39	56	27				
6			19	41	40	19				
7			11	20	30	16				
8			2	11	16	8				
9			2	7	12	12				
60			4	10	10	9				
1			1	2	2	5				
2				4	2	1				
3			1	1	1	2				
4				1	1	1				
Total		2	455	380	296	153				
Mean		48.5	52.5	53.5	55.0	55.7				

West of 170°E—June

41										
2										
3				1						
4										
45			1							
6	1		1							
7			4	2						
8		2	6	1						
9	3		17	12	3					
50	1	3	58	47	5	7				
1			73	43	20	5				
2		1	82	60	25	11				
3			97	80	40	26				
4			109	79	61	22				
55			110	80	111	37				
6			61	74	92	31				
7			54	48	68	27				
8			22	42	76	31				
9			9	26	63	20	1			
60			8	21	58	30				
1			3	8	19	14				
2				9	13	16				
3				4	7	7				
4			1	1	7	4				
65				1	1	4				
6						2				
7						2				
8										
9						1				
Total	5	6	716	639	669	297	1			
Mean	48.6	49.7	53.6	54.6	56.5	57.1	59.0			

Continued.

G-8. Chum, 1960 (Continued).

West of 170°E—July

	3		4		5		6		7	
Length	F	M	F	M	F	M	F	M	F	M
41										
2		1		1						
3		1								
4	4	2	1	1						
45	11	12	6							
6	15	28	6	3						
7	19	24	19	19						
8	29	59	42	26						
9	39	68	69	59	1	1				
50	32	45	126	101	11	2				
1	26	40	172	133	10	7				
2	14	30	209	199	11	14				
3	9	22	234	204	47	17				
4	10	9	237	218	52	38				
55	6	8	251	205	96	34	1			
6	1	4	223	147	87	45				
7		1	206	123	101	40				
8			142	86	95	36				
9			91	56	84	33	1			
60			45	45	87	23				
1			23	22	45	13				
2			11	16	38	11				
3			3	15	17	11				
4			3	5	8	8				
65			2	1	3	5				
6				1	1					
7				1		2				
8						3				
Total	215	354	2,121	1,687	794	343	2			
Mean	49.4	49.5	54.2	54.1	57.3	57.2	57.0			

West of 170°E—August

41										
2										
3										
4	1									
45										
6		2	1							
7	1	3	1	1						
8	4	2	1							
9	3	4	1	1						
50	7	2	1	1						
1	1	3	3	6	1					
2	1	2	6	9		1				
3		1	6	3	3	2				
4	1		8	10						
55		1	5	5	4	2				
6		2	7	4	2					
7			4	5	1	1				
8			8	3	2					
9			4	5						
60			5							
1			2							
2			1	1						
3					2					
4			1							
Total	19	22	65	54	15	6				
Mean	49.3	50.1	55.4	54.3	56.1	54.2				

Continued . . .

G-8. Chum, 1960 (Continued).

Landbased, South of J-S Treaty Line—May

	3		4		5		6		7	
Length	F	M	F	M	F	M	F	M	F	M
40		1								
1										
2										
3										
4		2								
45	1	1								
6	2	1	1	2						
7	1	3	3	3						
8	1	3	11	5	1					
9	1		25	14	2					
50	1	2	31	17	3	3				
1	2	2	31	27	2	2				
2	1	1	22	29	1	1				
3		3	25	24	5	1				
4	1	2	23	31	11	7		1		
55		1	21	23	14	3	1			
6	1		15	22	8	8				
7			9	25	15	12				
8			12	18	17	11				
9			3	12	8	7				
60			1	5	14	14				
1			3	2	5	6				
2				1	3	2				
3				1	3	3				
4			1			2				
65						1				
6										
7					1					
Total	12	22	237	261	113	83	1	1		
Mean	49.6	49.1	52.6	53.9	56.9	57.8	55.0	54.0		

Landbased, South of J-S Treaty Line—June

41										
2										
3	1			2						
4										
45		1		1						
6		3	1							
7	2	1	1	2						
8	2	4	4	3						
9	2	3	6	6						
50	3	10	8	12		1				
1	6	8	14	12						
2	5	2	35	11						
3	2	3	54	38	1	2				
4		4	88	44	3	1				
55	5	2	72	49	12	4				
6	1	1	71	60	15	10				
7			62	65	35	15				
8		1	46	52	19	25				
9			24	35	26	15				
60			13	27	21	16		1		
1			11	11	18	7				
2			6	9	7	8				
3			1	2	6	8				
4					1	4				
65				1						
6						1				
7										
8						1				
Total	29	43	517	442	164	118		1		
Mean	51.2	50.7	56.2	57.1	58.4	59.0		60.0		

Continued.

G-8. Chum, 1960 (Continued).

Landbased, South of J-S Treaty Line—July

	3		4		5		6		7	
Length	F	M	F	M	F	M	F	M	F	M
41										
2										
3		1								
4	2	3								
45	4	9								
6	12	12	1							
7	22	20	2	2						
8	17	23	4							
9	16	27	6	5	1					
50	18	27	14	13						
1	11	22	13	17						
2	6	13	23	28	1	1				
3	5	12	27	15	1					
4	5	8	34	27	2	2				
55	1	5	27	24	1	1				
6	3		32	13	3					
7	4	1	34	21	9	5				
8			24	24	10	5				
9			19	16	7	1				
60			13	10	3	4				
1			9	13	5	2				
2			6	7	2	1				
3			3	7	5	4				
4			2	6		2				
65				1	1	1				
6				1						
7				2						
Total	126	183	293	252	51	29				
Mean	49.3	49.4	55.3	55.8	58.4	59.2				

Landbased, North of J-S Treaty Line—July

40		2				
1						
2						
3	2	5				
4	8	3		1		
45	9	19		1		
6	19	28	2			
7	25	16	4	1		
8	25	24	2	4		
9	35	26	6	6		
50	31	50	16	9		
1	32	36	26	11		1
2	13	21	20	23		
3	5	18	26	26	2	
4	7	15	37	25	1	
55	3	8	39	32	1	
6		1	43	20	5	2
7	1		26	26	3	3
8			29	18	5	4
9			16	22	8	
60		1	23	12	6	6
1			4	6	6	2
2			4	4	3	2
3			2	2	2	2
4				2		
65			1		2	1
6					1	
7			1			
8			1	2		1
72				1		
Total	215	273	328	254	45	24
Mean	49.0	49.4	55.1	55.3	59.2	59.6

Continued . . .

G-8. Chum, 1960 (Continued).

Landbased, North of J-S Treaty Line—August

	3		4		5		6		7	
Length	F	M	F	M	F	M	F	M	F	M
41										
2										
3		1								
4										
45		2								
6	4	4								
7	7	9	1							
8	18	13	3							
9	18	10	4	1						
50	15	19	2	2						
1	10	11	3	3						
2	11	11	9	3						
3	6	8	6	5	1					
4	2	5	7	13						
55	1	2	14	7						
6		2	5	6		1				
7	1		17	9						
8			11	8	2	1				
9		1	7	1						
60			4	2	1	1				
1			2	2	1					
2			2	4	2					
3			2			1				
4				1		1				
65				1	1					
6			1		1					
7					1					
Total	93	98	100	68	10	5				
Mean	49.8	50.1	55.5	55.9	61.2	60.2				

G-9. Pink, 1957.

East of 170°E

	May		June		July		August	
Length	F	M	F	M	F	M	F	M
35								
6								
7								
8		2						
9		6						
40	1	11		3				
1	1	18	1	9				
2	3	37	3	22				
3	6	66	14	54	1	2		
4	2	151	28	176	10	3		
45	3	270	93	397	11	11		
6	1	267	91	442	15	14		
7		301	105	506	33	21		
8		217	87	484	46	24		
9		155	47	456	28	31		
50		113	26	392	33	45		
1	1	35	7	216	13	38		
2		22	3	174	1	34		
3		5	2	79		18		
4		3		46		4		
55		1		28		7		
6				9		4		
7				3		1		
8				2		1		
9				1				
Total	18	1,680	507	3,499	191	258		
Mean	44.6	46.5	46.8	47.9	48.0	49.9		

West of 170°E

35						
6		1				
7		2				
8	1	2	1			
9	4	20		3	1	
40	14	58		16	1	2
1	7	73	5	39	8	3
2	6	121	10	77	9	37
3	10	207	25	194	54	101
4	4	341	59	387	194	200
45	6	518	120	747	390	471
6	3	474	78	724	482	610
7		374	27	624	423	582
8	1	306	14	464	276	526
9		220	7	278	114	334
50		128	4	201	48	269
1		28		72	14	127
2		18		31	5	65
3		8		15	1	35
4		4		4	1	11
55		1		6		3
6				4		1
7		3		2		1
8		2				
9		2				
Total	56	2,911	350	3,888	2,021	3,380
Mean	42.1	45.8	45.2	46.3	46.3	47.1

Continued . . .

G-9. Pink, 1957 (Continued).

Okhotsk Sea

	May		June		July		August	
Length	F	M	F	M	F	M	F	M
35								
6								
7								
8								
9				1				
40			1	2				
1			1	2		1		
2			5	17	4	11		
3			2	51	5	25		
4			14	91	22	60		
45			16	132	64	131		
6			14	192	78	161		
7			16	170	63	134		
8			4	95	53	92		
9			3	72	24	56		
50				49	18	40		
1				22	3	20		
2				11	1	7		
3				3	2	2		
4				4		2		
55				2				
6				1		1		
7						2		
8						1		
Total			76	917	337	746		
Mean			45.4	46.5	46.6	46.7		

Landbased, South of J-S Treaty Line

35		1		
6				
7				
8				
9				
40		3		1
1		3	3	1
2	3	3	7	8
3	4	7	9	24
4	7	14	14	27
45	7	45	26	48
6	4	58	16	52
7	5	60	16	48
8	3	43	12	32
9	2	43	1	26
50		24	3	23
1		12		10
2		3		3
3		3	1	
4				2
55				2
6				2
7		2		
Total	35	325	108	309
Mean	45.2	47.0	45.4	46.6

Continued

G-9. Pink, 1957 (Continued).

Landbased, North of J-S Treaty Line

	May		June		July		August	
Length	F	M	F	M	F	M	F	M
40					1			
1								
2					2			
3				1	6	5		
4			1	1	19	6	1	
45			2		19	9	1	
6			1	1	29	11	4	2
7				2	16	12	6	3
8			1		7	8	2	4
9					5	3	8	1
50					6	2	7	2
1				1	1	5	3	3
2						2	1	
3						1	1	4
4					1		1	
55							1	
6								
7								1
Total			5	6	112	64	36	20
Mean			45.6	46.3	45.9	46.8	48.9	49.8

G-10. Pink, 1958.

East of 170°E

	May		June		July		August	
Length	F	M	F	M	F	M	F	M
40	1	1	2	1				
1		2	1	3				
2	1	2	10	6				
3	2	4	16	15				
4	1	25	46	45				
45	8	61	85	115				2
6	8	107	77	172				1
7	4	162	53	268			7	1
8	8	237	32	287			8	10
9	2	214	16	220			18	12
50	1	214	5	197			40	9
1	2	90	5	94			28	7
2	1	39	2	36			25	17
3		22		20			15	18
4		10		2			11	13
55		3		2			2	13
6							4	6
7		2		1			1	10
8		2					1	6
9		5						1
60								4
Total	39	1,202	350	1,484			160	130
Mean	46.5	48.5	45.8	47.9			51.0	52.8

West of 170°E

35								
6								
7								
8				1				
9			1					
40			7	5		1		
1	1	2	10	12	4	5		1
2	10	4	45	42	14	9		2
3	6	16	138	142	33	33	1	1
4	10	58	311	321	122	99	14	8
45	16	179	521	596	318	247	61	25
6	13	283	479	761	525	335	49	38
7	14	479	331	855	784	522	95	40
8	6	496	169	913	924	633	116	52
9	2	419	67	706	892	686	186	64
50	2	260	36	578	725	789	241	96
1	2	111	11	301	411	629	250	90
2		41	5	152	219	446	237	107
3		20	1	60	89	345	184	112
4		7		30	34	220	87	135
55		3		11	15	119	60	117
6			2	3	5	56	6	80
7				1	4	29	2	50
8				1	3	7		42
9						3	1	17
60								3
1								1
Total	82	2,368	2,134	5,491	5,121	5,213	1,590	1,081
Mean	45.4	47.9	45.7	47.5	48.3	49.5	50.4	52.3

Continued

G-10. Pink, 1958 (Continued).

Okhotsk Sea

	May		June		July		August	
Length	F	M	F	M	F	M	F	M
40				1		1		
1				7	1			
2			10	29	3	6		
3			26	53	11	3		1
4			39	83	41	34		2
45			58	109	54	36	2	4
6			33	159	91	34	3	3
7			27	83	82	41	12	2
8			10	79	89	36	18	10
9			6	42	68	29	24	12
50				30	68	38	37	13
1			1	13	35	30	16	12
2				5	11	25	17	11
3				3	5	10	8	7
4			2			10	2	13
55					1	1		11
6				1		2	2	3
7						2	1	3
8						1		1
9						1		
Total			212	697	560	340	142	108
Mean			45.2	46.0	47.5	48.2	49.9	51.1

Landbased, South of J-S Treaty Line

39	1		2					
40	2			8				
1	4	5	7	19				
2	14	15	12	20	1			
3	12	30	41	43	2	1		
4	16	47	48	65	6	3		
45	29	61	58	84	5	5		
6	13	61	61	123	17	7		
7	4	49	52	86	26	7		
8	8	42	30	105	34	14	2	2
9	1	25	27	77	30	14	3	
50		11	8	54	31	19	2	3
1		6		33	13	15	9	5
2		7	3	13	11	16	5	6
3				11	5	6	6	4
4				8	1	4	2	2
55				3		2	1	4
6				1		3		2
7				1				
8								1
9						1		
Total	104	359	349	754	182	117	30	29
Mean	44.4	46.0	45.6	46.8	48.5	49.8	51.4	52.5

Continued . . .

G-10. Pink, 1958 (Continued).

Landbased, North of J-S Treaty Line

	May		June		July		August	
Length	F	M	F	M	F	M	F	M
39				2				
40			1	2		1		
1			4	2	1	5		
2	2	5	8	15	4	7		
3		3	16	13	11	5		
4		9	30	30	23	14		
45		13	30	39	41	33	3	2
6		6	24	36	87	56	4	1
7	1	10	23	27	108	52	11	2
8		6	17	39	131	55	31	13
9		5	7	26	84	40	46	7
50		1	2	17	43	34	49	19
1			1	7	21	28	42	10
2				2	16	17	22	8
3				9	3	5	12	13
4				9	2		4	12
55				1		2	5	8
6			1	2		3		2
7				2				
8								2
Total	3	58	164	279	575	357	229	99
Mean	43.7	45.7	45.4	46.9	47.5	47.7	50.0	51.3

G-11. Pink, 1959.

East of 170°E

	May		June		July		August	
Length	F	M	F	M	F	M	F	M
39			1					
40			3	2		1		
1			2	8	2	2		
2			11	25	8	16		
3		3	24	73	26	46		
4		9	60	163	76	95		
45	1	23	105	335	155	203		
6	2	38	141	412	223	254		
7	1	63	115	460	256	248		
8		61	88	470	251	250		
9	1	71	51	382	197	214		
50		20	24	334	131	190		
1	1	12	14	161	50	125		
2		9	6	91	21	83		
3		2	2	31	8	46		
4		2	2	16	6	28		
55			2	17		29		
6				2	1	8		
7				3		7		
8				1		3		
9					1	3		
Total	6	313	651	2,986	1,412	1,851		
Mean	47.8	48.4	47.0	47.4	47.9	48.5		

West of 170°E

39			1	1		
40			2	3	3	3
1		2	6	15	8	5
2	1	1	24	24	20	18
3		5	90	72	76	51
4	7	21	205	177	151	102
45	9	101	363	307	296	184
6	7	177	360	184	347	198
7	12	345	206	686	339	244
8	12	444	156	783	227	205
9	4	386	87	758	176	186
50		346	57	642	144	194
1		156	10	559	56	122
2		36	4	212	26	93
3	3	13	1	135	11	88
4		4	1	58	6	46
55				20	6	28
6		1		20		7
7		2		7		8
8				5		4
9				1		
60				1		
Total	53	2,040	1,673	4,670	1,892	1,786
Mean	47.0	48.8	46.5	48.2	47.4	48.6

Continued . . .

G-11. Pink, 1959 (Continued).

Landbased, South of J-S Treaty Line

	May		June		July		August	
Length	F	M	F	M	F	M	F	M
37	1		1					
8		1						
9	1		1	1				
40	3	7		8				
1	5	13	6	9				
2	14	35	39	35				
3	17	90	68	58				
4	30	116	103	69		1		
45	26	157	156	136	3	1		
6	17	137	112	152	1	3		
7	6	79	79	128	3			
8	3	45	68	108	6	4		
9		23	40	67	4	2		
50		7	24	65		1		
1		3	11	40	1			
2			3	19				
3				11				
4				15				
55		2		2				
6		1						
7		1		1				
8			1	1				
Total	123	717	712	925	18	12		
Mean	44.5	45.7	46.2	47.3	48.1	47.8		

Landbased, North of J-S Treaty Line

39				1				
40					1	2		
1			1	2	1	2		
2			12	8	8	9		
3			12	11	31	21		1
4			27	20	54	24	1	1
45			47	34	114	64	3	
6			29	45	150	66	11	7
7			19	20	145	71	4	8
8			8	14	144	73	27	17
9			2	6	113	60	19	18
50			2	8	93	50	23	13
1			1	4	45	34	16	20
2			3	2	22	23	20	17
3			2		2	19	19	19
4			2	1	2	9	15	19
55			1	1	2	3	10	11
6			1			2	4	12
7			1			3	3	19
8				1	4	3	6	3
9			1		3	1	1	6
60							2	4
1						1	9	12
Total			171	178	934	540	195	202
Mean			46.2	46.5	48.0	48.4	52.2	52.7

G-12. Pink, 1960.

East of 170°E, South of 52°N

	May		June		July		August	
Length	F	M	F	M	F	M	F	M
39			1					
40		1	1	2				
1	2		5	4				
2	1	2	6	7		1		
3		1	7	28	2			
4		17	12	53	4	2		
45	1	25	26	109	3	4		
6	1	27	22	138	6	8	1	
7		32	11	158	19	15		
8		24	11	127	24	12	2	2
9		16	9	99	40	13		1
50		6	1	67	74	40		1
1		2		32	84	35	3	3
2		1		16	49	57	2	1
3		2		3	23	43	2	4
4					10	45		2
55					4	30	1	1
6					2	14		1
7					3	5		1
8					3	6		2
9					2			
60								
1						1		
Total	5	196	112	843	352	331	11	19
Mean	43.0	46.7	45.4	47.1	50.5	51.9	50.9	52.8

East of 170°E, North of 52°N

39				1				
40			2	3	1			
1			1	7				
2		1	6	17	2	2		
3			25	39	4	2		
4		1	42	72	6	6		
45			100	199	15	12	1	
6		7	99	318	11	14		1
7		5	103	397	16	33	2	2
8		9	74	418	9	38	3	2
9		1	35	381	2	34	6	1
50			19	361	2	23	8	7
1		1	6	188		11	6	2
2		1	5	90		5	9	8
3			2	40		6	4	8
4	1			15		4		8
5				4		1		5
6				3		1	2	1
7				2				1
8			1	3			1	
9			1	3				1
60				1				
Total	1	29	521	2,562	68	192	42	47
Mean	54.0	47.4	46.4	48.1	45.9	48.3	50.8	52.3

Continued

G-12. Pink, 1960 (Continued).

West of 170°E

	May		June		July		August	
Length	F	M	F	M	F	M	F	M
40	3	3	2	5	2	2		
1	1	3	2	2	5	6		
2	9	9	10	20	10	7		1
3	6	24	20	58	27	19		
4	7	77	52	147	62	56		
45	8	168	77	294	143	141		
6	3	209	41	366	221	195		1
7		218	23	371	292	278	1	
8		155	13	305	353	358	2	3
9		103	5	200	296	399	7	2
50		58	1	118	311	467	8	2
1		16	2	37	206	457	5	
2		6		15	121	398	6	4
3		1		7	54	222	5	5
4				2	16	130	1	4
55		1	2	1	5	79		1
6				1	2	35		4
7		1		1		10		
8					2	7		2
9		1			1	6		
60						2		
1						1		
Total	37	1,053	250	1,950	2,129	3,275	35	29
Mean	43.3	46.7	45.2	46.8	48.4	49.8	50.6	52.2

Landbased, South of J-S Treaty Line

34	1	1				
35	2					
6		5				
7	7	9		1		1
8	35	30	3	3	1	1
9	52	38	10	6	1	1
40	48	51	24	18	5	9
1	24	84	56	38	4	11
2	29	112	121	69	15	12
3	32	155	173	117	20	23
4	13	176	201	140	76	41
45	8	130	141	168	101	47
6	1	97	69	134	86	46
7	1	49	42	107	119	51
8		20	13	65	87	49
9	1	12	7	37	69	37
50		12	7	22	26	31
1		5	1	9	4	25
2		3	1	6	7	16
3				3	1	4
4		2		1		5
55						1
6						1
7						
8						
9						1
Total	254	991	869	944	622	413
Mean	40.5	43.4	43.8	45.0	46.4	46.8

Continued

G-12. Pink, 1960 (Continued).

Landbased, North of J-S Treaty Line

	May		June		July		August	
Length	F	M	F	M	F	M	F	M
40					1	1		
1								
2					1			
3			4		1	2	1	6
4			2		11	12	1	6
45			8	1	19	12	4	8
6			8	1	48	32	6	11
7			3	2	85	51	12	10
8				1	96	58	16	12
9					118	59	15	9
50					112	72	17	8
1					83	71	25	22
2					57	72	23	19
3					20	41	3	17
4					9	25	3	3
55					2	19	6	7
6						3		
7						1		
8						1		2
9						1		
Total			25	5	663	533	132	140
Mean			45.2	46.6	49.0	49.9	49.9	49.6

G-13. Coho, 1957.

East of 170°E

	May		June		July		August	
Length	F	M	F	M	F	M	F	M
48		1	1	1				
9								
50		1	1	4				
1				2		2		
2		1		1	1			
3	1	2			1			
4	1	1			1	1		
55				1	1	4		
6				1	4	1		
7					2	4		
8					1			
9						2		
60						1		
1					1			
2						2		
Total	2	6	2	10	12	17		
Mean	53.5	51.7	49.0	51.3	55.9	56.6		

West of 170°E

44			1			
45					1	2
6						3
7					2	14
8			3		7	11
9			2	5	6	10
50			4	11	17	22
1			9	11	16	25
2			13	14	28	35
3		1	14	17	34	34
4			6	8	46	38
55			10	16	50	63
6			1	8	45	34
7			3	8	43	35
8				6	34	27
9				3	21	14
60			1		7	8
1					1	6
2					1	7
3						
4						
65						1
Total		1	67	107	359	389
Mean		53.0	52.6	53.5	54.7	54.1

Continued

G-13. Coho, 1957 (Continued).

Okhotsk Sea

	May		June		July		August	
Length	F	M	F	M	F	M	F	M
45						1		
6						1		
7						1		
8				1	2	1		
9					1	4		
50				1	7	16		
1					14	13		
2			3	1	14	15		
3			1		37	32		
4			4	6	43	35		
55			3	4	70	38		
6			6	7	53	47		
7			2	5	46	55		
8			3	1	32	41		
9			1	3	18	26		
60				1	3	17		
1				1	6	8		
2						7		
3					1	2		
4					1			
Total			23	31	348	360		
Mean			55.3	55.7	55.3	55.7		

Landbased

44					1			
45								
6								
7								
8						1		
9								
50					2	1	1	
1								
2					6	4		
3					4	4		1
4			1		7	3		
55					6	5		
6					4	3		1
7				1	4	3		
8					4	7	1	1
9					5	3		
60					3	4	2	
1						3	1	1
2					1			
3					1	1		
4							1	
Total			1	1	48	42	6	4
Mean			54.0	57.0	55.4	56.3	58.8	57.0

G-14. Coho, 1958.

East of 170°E

	May		June		July		August	
Length	F	M	F	M	F	M	F	M
50							1	2
1				1			1	2
2			1	1			1	3
3			2	1			1	1
4				4			3	2
55				1			4	7
6							8	4
7							5	8
8							18	4
9							7	3
60							9	5
1							3	1
2							4	2
3							3	3
4							1	3
65							1	
Total			3	8			70	50
Mean			52.7	53.4			58.1	57.2

West of 170°E

42				1	1	4		
3						2		
4					1			2
45		1		2	2	9	1	1
6			1	2	1	20		6
7			2	9	3	26	1	7
8			3	2	12	42		3
9			4	15	16	48	5	14
50			21	26	42	79	15	30
1			26	38	47	112	13	40
2		2	46	47	82	107	18	46
3	1		59	67	150	128	23	52
4			57	46	203	171	48	56
55			61	83	293	212	57	101
6			31	62	299	190	69	91
7			28	32	321	207	87	65
8	1		12	32	274	231	66	65
9			2	19	181	139	93	46
60			2	10	138	126	64	53
1				1	66	90	53	25
2				1	38	50	21	28
3					15	24	13	7
4					4	14	6	12
65					2	6	3	6
6					2	2	3	3
7						1		3
8					1			1
9								
Total	2	3	355	495	2,194	2,040	661	577
Mean	55.5	49.7	53.7	54.1	56.2	55.5	57.3	56.2

Continued

G-14. Coho, 1958 (Continued).

Okhotsk Sea

	May		June		July		August	
Length	F	M	F	M	F	M	F	M
47								1
8						1		
9					2			1
50					4	3		2
1						2		1
2					7	3	1	2
3					7	4	1	3
4					14	4		4
55					10	8	3	4
6					14	7	4	6
7					21	15	7	5
8					17	6	7	10
9					15	5	2	2
60					10	10	4	5
1					9	10	2	6
2					4	7		1
3					3	3	3	3
Total					137	88	34	56
Mean					56.8	57.4	57.9	56.8

East of 170°E

	May						June										July							
	3_2		4_3		5_4		3_2		4_2		4_3		5_3		5_4		6_4		3_2		4_2		4_3		5_3		5_4	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
45							1												1	1			1					
6												1							1	2								
7								1				4			1	1			1	1			1	1				
8							1	2			5	1			1	1			1	1								
9							3	5			8	6			1				1	2			2	4			1	
50							7	1		1	7	3			1	1			3				6	4				
1	1		1	2			2	6			13	8		1					4	3	1		3	3				1
2							1	8			11	14		1	2	2		1	6	1			5	4			1	1
3							1	4			9	9		1	2				5	1			5	1				1
4							2				5	13			1				6	7			8	4			1	1
55									1		5	3				2			7	7			13	11			1	4
6											1	4							4	4			7	8			1	
7												5		1					1	2			5	6				
8											1	3								4			9	3				1
9												2								1			7	5				
60																				3			4	1				
1												1																
2																								1				
3																												
4																												
65														1														
6																												
7																							1					
Total	1		1	2			18	27	1	1	65	77		5	9	7		1	41	40	1		77	56			5	9
Mean	51.0		51.0	51.0			50.3	50.8	55.0	50.0	51.6	52.8		55.6	50.9	51.3		52.0	52.6	54.0	51.0		55.0	54.6			53.2	54.2

Continued . . .

G-15. Coho, 1959 (Continued).

West of 170°E

	May						June												July									
	3_2		4_3		5_4		3_2		4_2		4_3		5_3		5_4		6_4		3_2		4_2		4_3		5_3		5_4	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
45								2			1	1				1				1				2				
6								1			2	2				1				4								
7							5	3	1		2	5				1			2				2	1				
8							5	2			1	10							1	4			1	8				1
9							5	11			10	7							2	4			6	2				
50			1	2		1	9	17		1	21	20			1				4	7		1	8	7				3
1			1	1		1	14	9			18	18				2			6	7	1		7	9			1	
2			1	1			18	12			23	16			2	1			10	7	1		16	21			1	
3				1			5	10			13	21		1	2	3			16	16			14	14				1
4		1					3	7			16	20	1		2				10	13			20	16				2
55				1			3	8			8	11				1			6	9	1		16	14	2		2	
6							1	6		1	2	9			1				10	11			11	12			2	
7											1	9				1			10	4			12	7			4	1
8								2											3	5			9	8			1	2
9												3								1			5	3			1	
60																			1	4			3	8				2
1																			1	2			1	1				
2																				1			2	2				
3																								2				
Total		1	3	6		2	68	90	1	2	118	152	1	1	8	11			82	100	3	1	133	137	2		12	12
Mean		54.0	51.0	51.8		50.5	51.0	51.6	47.0	53.0	51.7	52.2	54.0	53.0	53.0	51.2			53.8	53.5	52.6	50.0	54.2	54.0	55.0		55.8	54.3

G-16. Coho, 1960.

East of 170°E, South of 52°N

	June				July								August					
	3_2		4_3		3_1		3_2		4_3		5_4		3_2		4_3		5_4	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
46								2	1									
7								1		1								
8								1		1	1							
9								2		2				1				
50				1			1		1	1								
1								1	2	5								
2		1					1	2	5	3	2							
3			1				3	5	4	5					1	1		
4			1	1			4	3	5	3		1				1		
55				1	1		3	4	10	2	1							
6				1			9	4	10	8	1							1
7							6	4	11	6		1						
8							2	4	12	12	1							
9							1	2	8	10	1				1			
60							1	4	14	10								
1							1	1	4	1	3							
2									2	2		1						
3								2		1								
4																		
65										2								
Total		1	2	4	1		32	42	89	75	10	3		1	2	2		1
Mean		52.0	53.5	53.8	55.0		55.8	55.1	56.8	56.6	56.3	57.7		49.0	56.0	53.5		56.0

East of 170°E, North of 52°N

	June				August							
	4_3		5_4		3_2		4_3		5_4		6	
Length	F	M	F	M	F	M	F	M	F	M	F	M
49								1				
50								1				
1							1	1				
2			1									
3							4	1				
4					2		1					
55		1					1	1		1		
6							2	1				
7							1				1	
8							2	1	1			
9							1	2				
60								1				
Total		1	1		2		13	10	1	1	1	
Mean		55.0	52.0		54.0		55.1	55.0	58.0	55.0	57.0	

Continued

G-16. Coho, 1960 (Continued).

West of 170°E

	May		June										July								August					
	4_4		2_2		3_2		4_3		5_4		2_2		3_2		4_3		5_4		6_5		3_2		4_3		5_4	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
42															1											
3															1											
4																										
45																2										
6														2		1										
7													1	2		3										
8	1													4		5										
9							1	1						5	2	13	1							1		
50	1							1					1	6	6	21		1	1							
1					1		6	4					3	12	9	13		1								
2					1	5	1	2	1	1		1	9	10	21	22	3	1								
3			1			1	4	3					14	12	24	17	6	3								
4					1	2	8	5	1				11	12	34	32	2	2								
55					2	3	2	3					10	16	36	23	5						2			
6					1		1	6					12	9	55	38	8	3			1					
7					1	1		4		1			12	8	51	39	4	2						3		
8							1	3					10	14	31	25	6	2						1		
9						2		1			1		4	5	20	27	7		1					1		
60													5	1	18	25	1	2				2	1	1		
1													2	1	7	11	2	2								
2															1	3							1	1		
3															2	3									1	
4															1	3										
65							1									1							1			
6																1										
Total	2		1		7		14		25		33		2		2		1		1		94		119		320	
Mean	49.0		53.0		54.3		54.4		53.6		54.5		53.0		54.5		59.0		52.0		55.3		53.8		55.8	

	July				August					
	4_3		5_4		6_5		3_2		4_3		5_4	
Length	F	M	F	M	F	M	F	M	F	M	F	M
42												
3												
4												
45		2										
6		1										
7		3										
8		5										
9	2	13	1							1		
50	6	21		1	1							
1	9	13		1								
2	21	22	3	1								
3	24	17	6	3								
4	34	32	2	2								
55	36	23	5								2	
6	55	38	8	3			1					
7	51	39	4	2						3		
8	31	25	6	2						1		
9	20	27	7		1					1		
60	18	25	1	2				2	1	1		
1	7	11	2	2								
2	1	3							1	1		
3	2	3									1	
4	1	3										
65		1							1			
6		1										
Total	320	328	45	19	2		1	2	5	8	1	
Mean	55.8	55.4	56.1	55.8	54.5		56.0	60.0	59.4	57.4	63.0	

Continued

G-16. Coho, 1960 (Continued).

Landbased, South of J-S Treaty Line

	May		June								July							
	3_2		3_2		4_3		5_3		5_4		3_2		4_3		5_3		5_4	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
48		1															1	
9												1	2					
50					1						1	2	2	1			1	
1			1								1	2	1	5				
2											1		6	4				
3					1						3	2	4	3			1	1
4				1	3	1					5	1	4	9	1	1		
55						2			1		2	2	7	8	1			
6					2	2					3	1	7	9			3	
7					1	2					3	1	2	8				
8					1	2							7	3		1	1	
9												1	2	1				1
60						2						1		5				
1														1				
2								1										
Total		1	1	1	9	11		1	1		19	14	44	57	2	2	7	2
Mean		48.0	51.0	54.0	54.7	56.9		62.0	55.0		54.3	53.8	54.6	55.3	54.5	56.0	53.9	56.0

Landbased, North of J-S Treaty Line

	July										August							
	3_2		4_2		4_3		5_3		5_4		3_1		3_2		4_3		5_3		5_4	
Length	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
40		1																		
45																				
6						1														
7		1				1														
8						1														
9		1				1														
50		1			1	2									1					
1						2							1							
2	2	2			2	4		1	2					1		1				
3	2	2		1	8	4				1					2	1				
4	3	3			9	2				1			1	1	1	1		1		1
55	6	7			10	2			2	1			1		3	2				
6	4	3			15	8							2	1	2				1	
7	5	3			10	8			2	1			1	3	8	3				
8	3	2			17	5			1	1			1	1	3	3				
9	2	5			7	15		1		2				1	3	2				
60	2	2			5	3									10	5			1	
1		2			2	7			1		1		1	1	4	1			1	
2		1			1			1								1				1
3						2														
4																1			1	1
Total	29	36		1	87	68		3	8	7	1		8	9	37	21		1	4	3
Mean	56.0	55.5		53.0	56.4	56.5		57.7	55.9	56.4	61.0		56.0	56.8	57.8	58.0		54.0	60.3	60.0

G-17. Chinook, 1957.

East of 170°E

	May		June		July		August	
Length	F	M	F	M	F	M	F	M
41-42		1						
43-44			1					
45-46			2	7		1		
47-48		2	12	12	6	5		
49-50	1	1	27	18	19	15		
51-52		3	15	27	25	23		
53-54		6	15	23	8	11		
55-56	1	9	6	21	4	12		
57-58	2	6	5	15	4	8		
59-60	1	9	8	16	6	3		
61-62	3	2	8	20	4	2		
63-64	3	3	20	10	5	3		
65-66	4	7	22	13	6			
67-68	4	8	20	14	3	1		
69-70	2	3	10	7		1		
71-72	2	2	15	5				
73-74	2	2	1	6	2	1		
75-76	2	2	2	3	1	1		
77-78	1	2	2					
79-80	3	5	2	2				
81-82	2	2	2	1				
83-84	3	5	2	1				
85-86	2	1		2				
87-88	2	1	1	1				
89-90	4	5	1					
91-92	1	1	2					
93-94	3		1	1				
95-96	7	1	1					
97-98			1	1				
99-100	3	9	1	1				
101-102								
103-104								
105-106								
107-108								
109-110		1						
123-124		1						
Total	58	100	205	227	93	87		
Mean	78.3	70.7	61.7	59.1	55.2	54.1		

Continued . .

G-17. Chinook, 1957 (Continued).

West of 170°E

	May		June		July		August	
Length	F	M	F	M	F	M	F	M
43–44				1				
45–46								
47–48								
49–50								
51–52				1	1	3		
53–54		1	1	3	5	3		
55–56				4	7	7		
57–58			1	3	9	13		
59–60		1	5	8	15	19		
61–62		1	1	5	9	17		
63–64			3	2	10	15		
65–66	1	4	5	2	16	9		
67–68	1	4	2	2	8	8		
69–70		3		3	3	5		
71–72				1	2	2		
73–74					1	1		
75–76				1	1			
77–78				1		1		
79–80		1	1					
81–82			2	1				
83–84								
85–86		1		1				
87–88								
89–90	1							
91–92				1				
93–94		1						
Total	3	18	21	40	87	103		
Mean	71.3	71.3	65.0	63.0	62.0	61.7		

Okhotsk Sea

49–50				1		2		
51–52				1		2		
53–54				1		4		
55–56				5	1	8		
57–58				6	2	5		
59–60				7	1	6		
61–62					2	8		
63–64				1	2	2		
65–66				1	2	4		
67–68						2		
69–70					1			
71–72					1			
73–74					1			
75–76					1			
77–78								
79–80						1		
81–82								
83–84								
85–86						1		
87–88				2				
89–90								
91–92								
93–94								
95–96								
97–98								
99–100			1			1		
101–102				1				
103–104								
105–106				1				
Total			1	27	14	46		
Mean			99.0	63.1	64.4	60.5		

G-18. Chinook, 1958.

East of 170°E

	May		June		July		August	
Length	F	M	F	M	F	M	F	M
35-40								
40-45		1	1					
45-50	1	3	4	1				
50-55	5	15	15	33			3	1
55-60	3	22	22	87			25	10
60-65	15	12	18	35			19	21
65-70	14	12	30	29			8	6
70-75	6	5	16	16			6	
75-80	3	2	11	8			1	
80 85	9	5	7	3				
85-90	6	3	5	3				1
90-95	8	3	2	4				
95-100	5	1		1				
100-105	2	1	2	3				
105-110	1							
110-115		1						
Total	78	86	133	223			62	39
Mean	74.9	64.9	66.6	62.7			61.9	62.

West of 170°E

35-40		1		12		2		
40-45		2		29	2	22		1
45-50	2	2	15	26	10	18	3	3
50-55	21	39	68	156	82	117	24	19
55-60	13	50	111	388	393	433	179	132
60-65	37	34	176	231	411	438	171	150
65-70	29	25	211	146	141	143	31	31
70-75	7	16	68	75	77	61	10	12
75-80	10	3	45	44	30	26	11	1
80 85	4	2	45	20	16	13	5	1
85 90	12	8	31	20	3	10		
90 95	10	12	42	21	2		1	
95-100	16	9	29	9		4		1
100 105	6	6	5	14				
105-110	2	2	2	4				
110-115		1		5				
Total	169	212	848	1,200	1,167	1,287	435	351
Mean	72.1	66.7	68.6	62.7	62.0	61.2	61.1	60

Okhotsk Sea

35-40								
40-45								
45-50			3					
50-55			10	8	1	3		
55-60			6	20	1	11	1	1
60-65			2	12	14	23	1	1
65-70				8	5	4		
70-75				2		1		
75 80								
80 85								
85 90			1					
90 95			1	1				
95 100								
Total			23	51	21	42	2	
Mean			57.3	60.7	63.0	61.2	60.0	60

G-19. Chinook, 1959.

East of 170°E

Length	May		June		July		August	
	F	M	F	M	F	M	F	M
35-40				2				
40-45								
45-50		1	4	2	6	7		
50-55		3	10	29	54	44		
55-60		4	22	61	56	60		
60-65	1	2	15	49	30	31		
65-70	1	1	21	16	28	14		
70-75		1	20	15	15	8		
75-80		1	9	4	9	2		
80-85			2	3				
85-90			4	2		1		
90-95	2		2					
95-100	1		3	1				
100-105			1	1				
105-110				1				
110-115								
Total	5	13	113	186	198	167		
Mean	82.6	59.7	67.0	61.7	60.0	58.6		

West of 170°E

35-40				1				
40-45		1	1	1				
45-50		1	2	4		4		
50-55		11	8	30	17	12		
55-60	2	42	29	81	47	55		
60-65	3	14	25	53	40	68		
65-70	8		14	28	12	19		
70-75	11	5	16	16	14	8		
75-80	2	5	6	14	8	3		
80-85	7	3	8		4	1		
85-90	10	7	4		1			
90-95	6	1	1					
95-100		1						
100-105	1	2						
105-110			1					
Total	50	93	115	228	143	170		
Mean	78.0	64.1	65.8	61.1	62.7	61.4		

G-20. Chinook, 1960.

East of 170°E, South of 52°N

	May		June		July		August	
Length	F	M	F	M	F	M	F	M
40-45						1		
45-50						1		
50-55			1	6	14	13		1
55-60	1	5	5	27	54	40		2
60-65	3	1	5	10	34	50	3	1
65-70	8	2	12	14	10	13		2
70-75	7	3	14	4	5	6	1	
75-80	1	3	6	3	5	3		
80-85	2		2	7		3		
85-90	2	1	5		1			
90-95	1	1	3					
95-100	1	1	1					
100-105		1	1	1				
Total	26	18	55	72	123	130	4	6
Mean	72.5	72.4	72.3	63.8	60.3	60.8	64.5	59.8

East of 170E, North of 52°N

40-45				1		1		
45-50			8	11	1			
50-55			87	88	12	14		1
55-60			88	109	14	13	1	5
60-65			65	81	6	12	3	8
65-70			107	54	10	5	4	3
70-75			57	35	5	1	2	
75-80			6	12	1	2	1	2
80-85				1				
85-90			1					
90-95			1					
Total			420	392	49	48	11	19
Mean			61.5	59.8	59.9	58.8	66.1	62.8

West of 170°E

40-45					1	3		
45-50			3	4	11	14		
50-55		4	20	33	34	64		
55-60	2	13	21	60	123	173	1	4
60-65	4	7	17	38	171	225	9	6
65-70	8	4	43	25	113	102	2	7
70-75	11	6	29	23	110	60		3
75-80	7	8	21	21	35	31		
80-85	8	8	9	8	9	11	1	
85-90	5	1	19	10	2	1		
90-95	5		8	5		1		
95-100	2	2	4	4				
100-105	2	2	2	2				
105-110			1					
110-115				1				
Total	54	55	197	234	609	685	13	20
Mean	77.3	69.4	70.2	65.4	64.0	62.0	64.2	64.9

Continued

G-20. Chinook, 1960 (Continued).

Landbased, South of J-S Treaty Line

	May		June		July		August	
Length	F	M	F	M	F	M	F	M
40-45						1		
45-50					1			
50-55	4	2		1	15	12		
55-60		1	2	3	26	34		
60-65			1	3	10	20		
65-70			2	1	5	7		
70-75		1	2	1	2	2		
75-80	1	1	3	1	2	2		
80-85		2	3	1		1		
85-90		1				1		
Total	5	8	13	11	61	80		
Mean	56.0	69.1	71.9	63.5	58.5	59.9		

Landbased, North of J-S Treaty Line

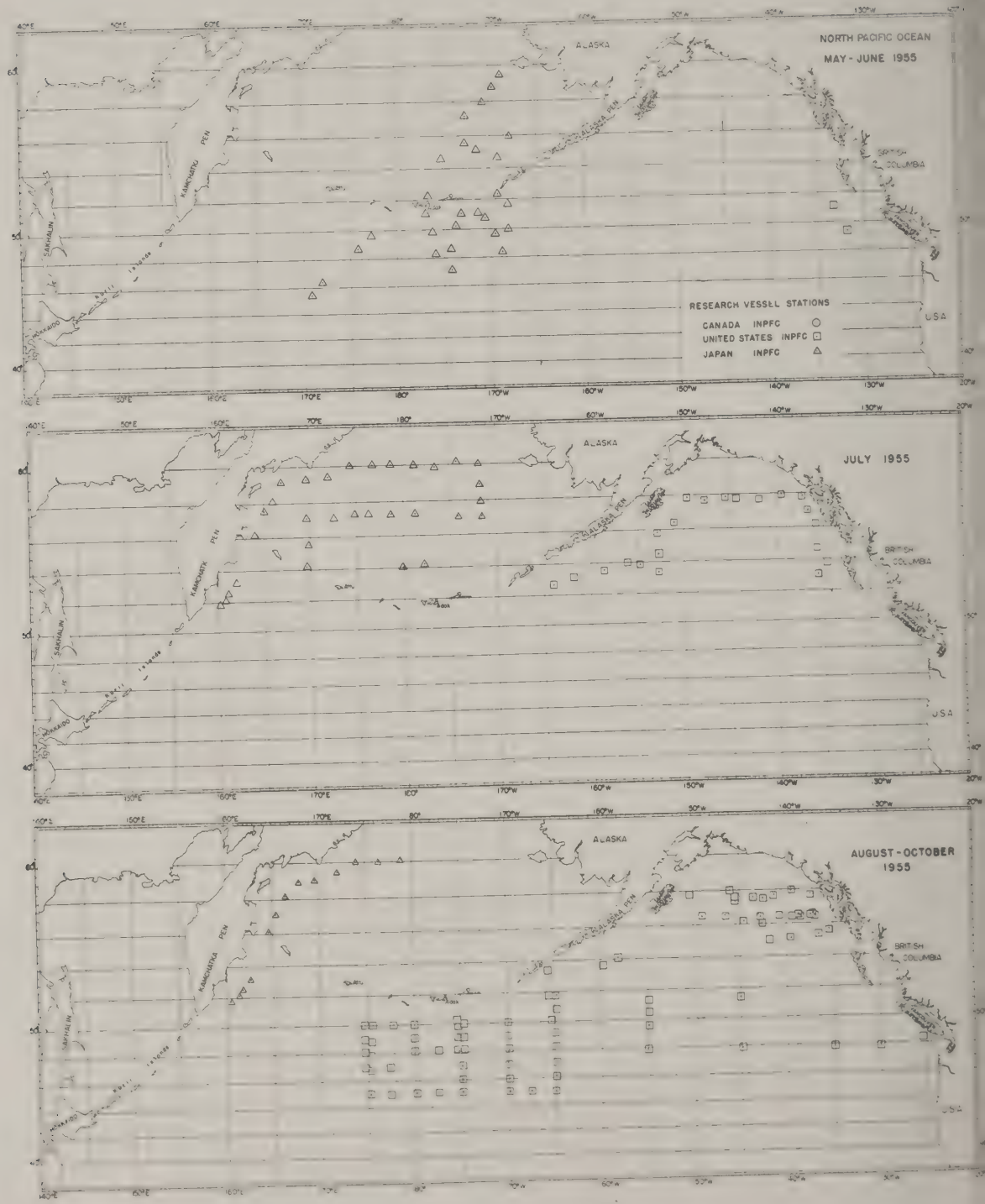
40-45								
45-50							1	
50-55					4	3	4	2
55-60					18	13	8	5
60-65					12	11	4	11
65-70					5	3		3
70-75					2	4	4	
75-80					1	1		1
80-85						1		
Total					42	36	21	22
Mean					60.1	61.8	59.9	60.7

APPENDIX FIGURE A. FISHING STATIONS OF GILLNET VESSELS OPERATED BY CANADA, JAPAN AND THE UNITED STATES AS PART OF THE INPFC RESEARCH PROGRAM, 1955–1960

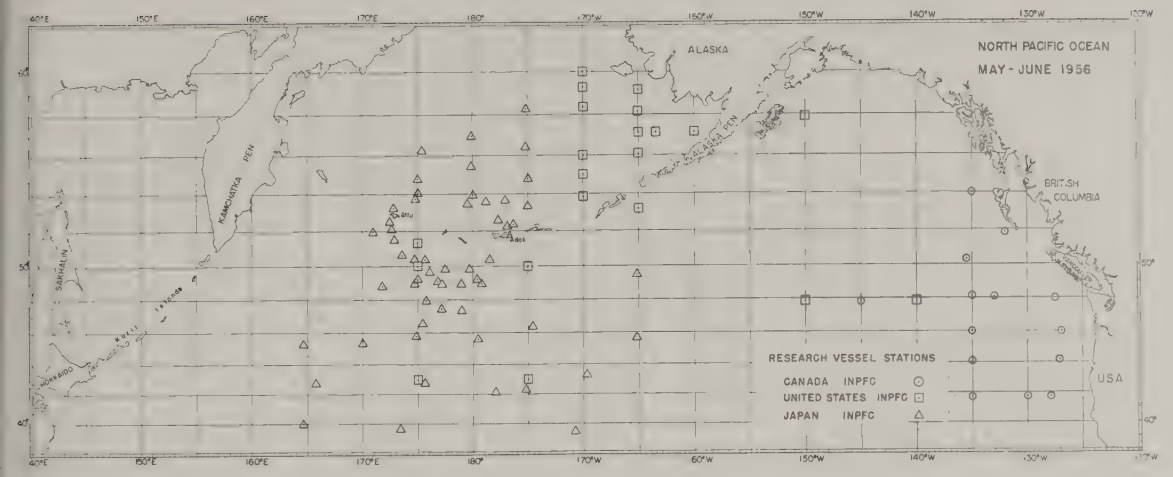
(Usually each station was fished only once during a short period of time. In instances where more than one set was made, the number is indicated by the numeral adjacent to the station position.)

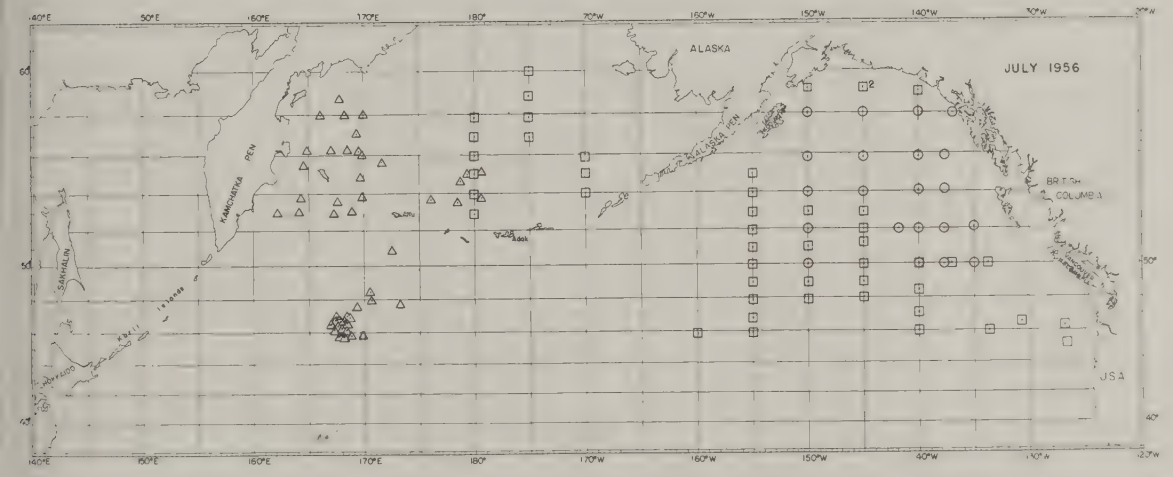
Page

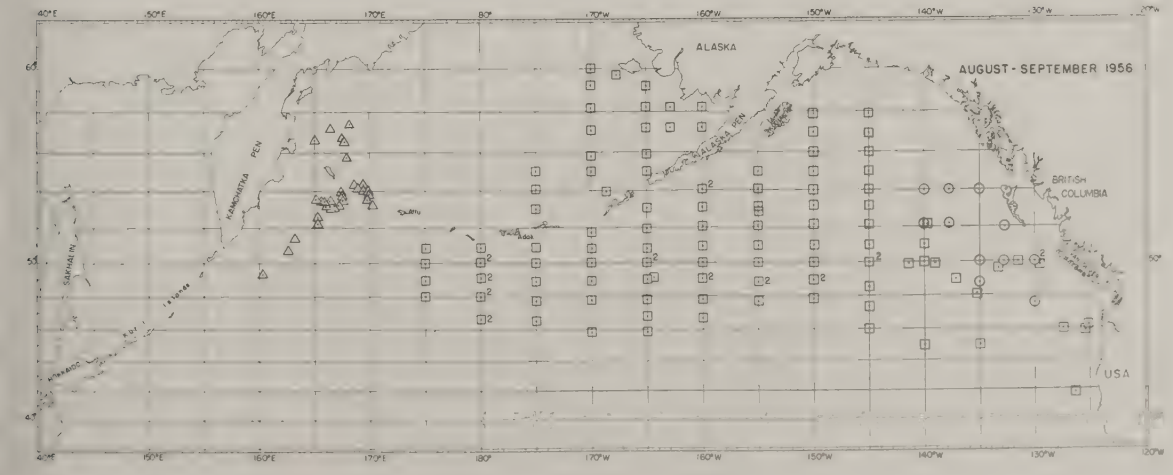
A-1. 1955 368
A-2. 1956 369
A-3. 1957 370
A-4. 1958 371
A-5. 1959 372
A-6. 1960 373



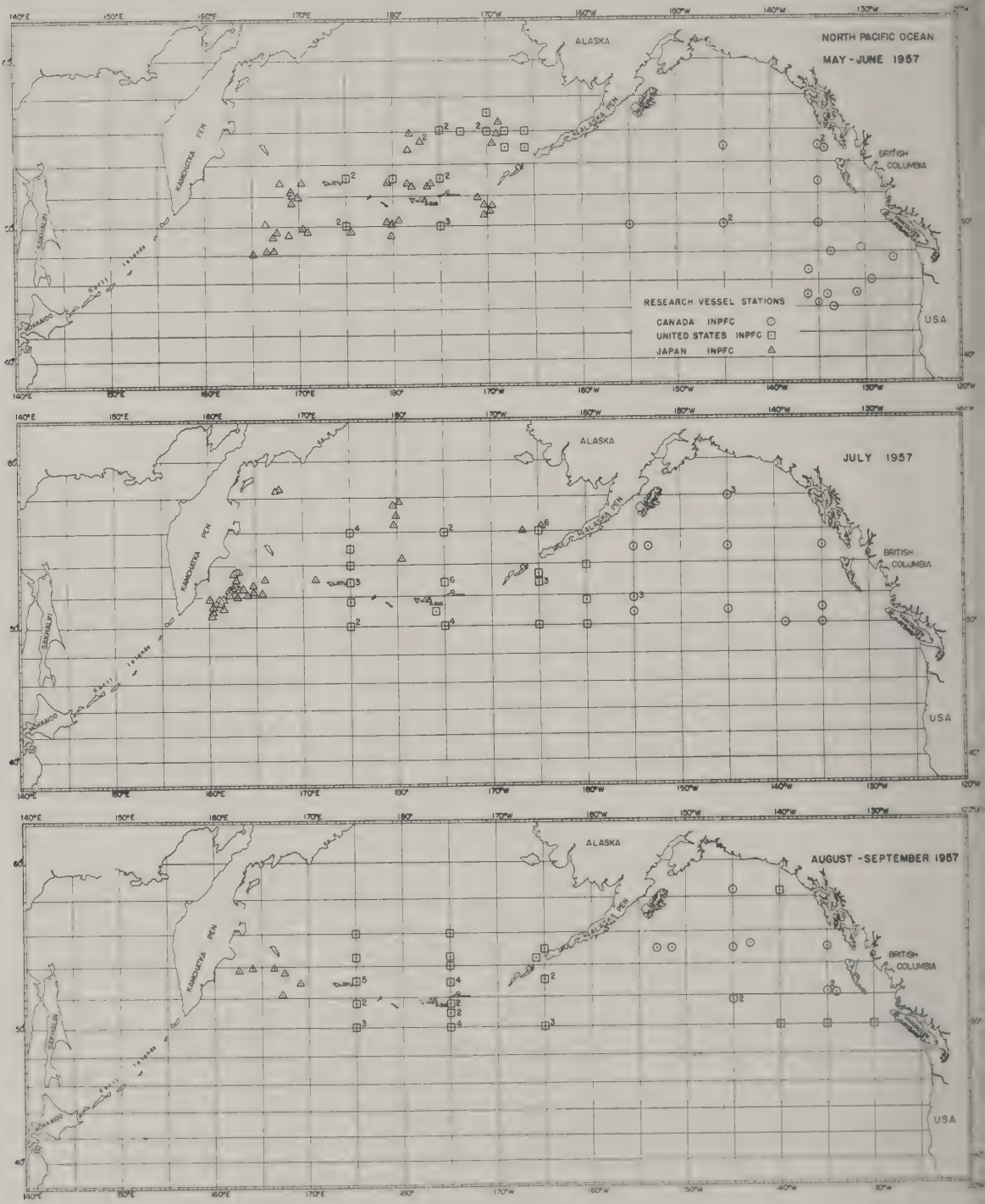
Appendix Figure A-1. 1955.



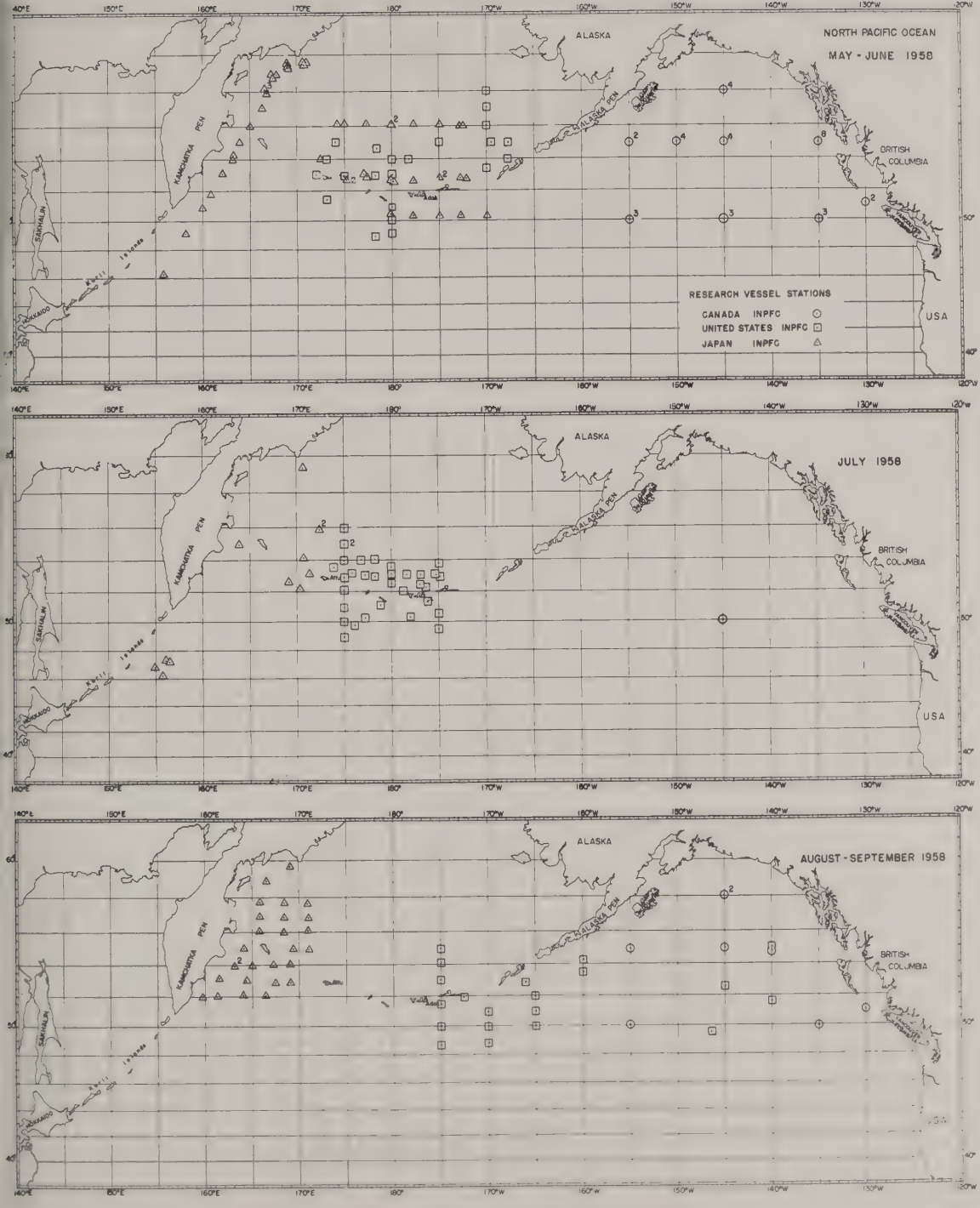




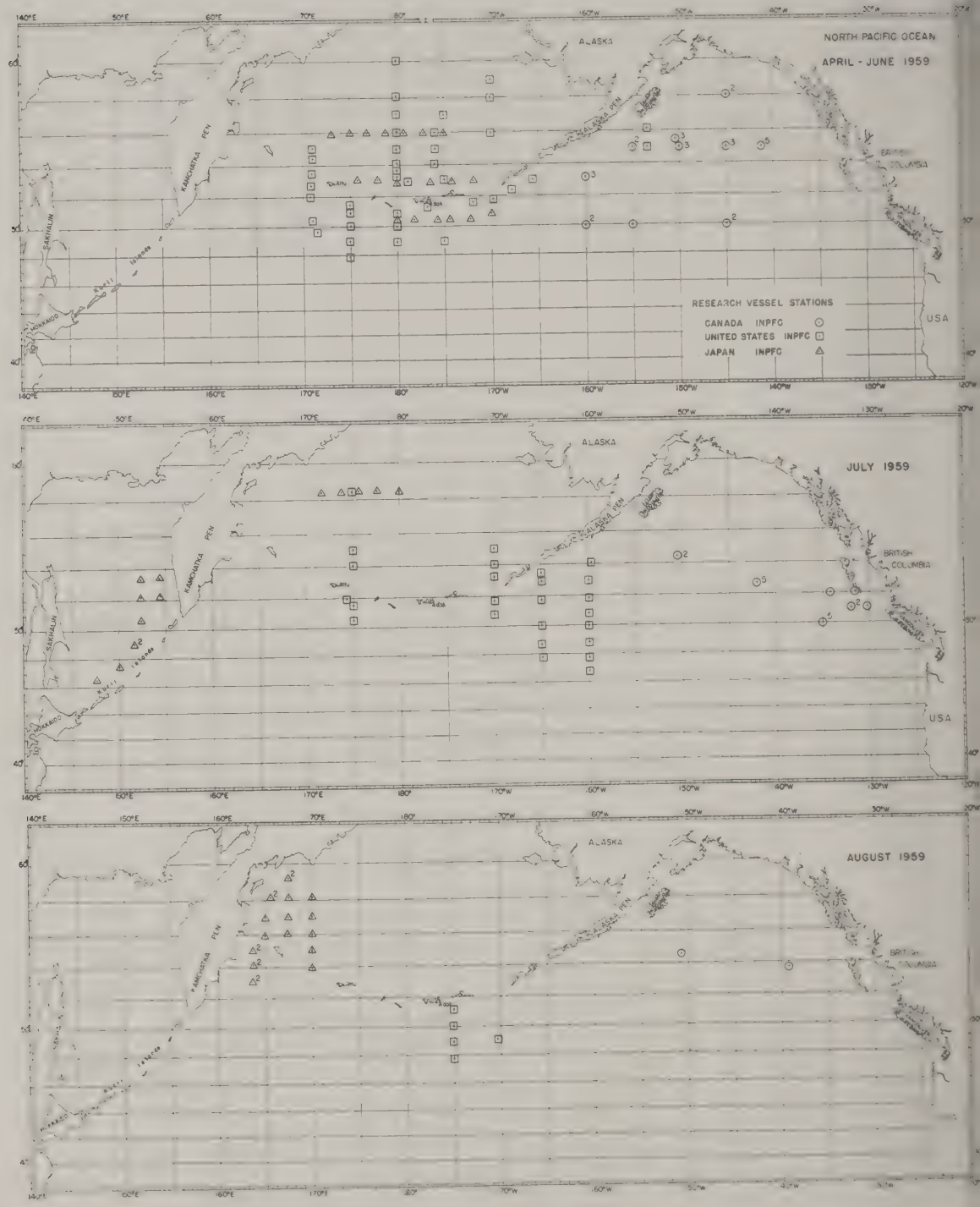
APPENDIX FIGURE A-2. 1956.



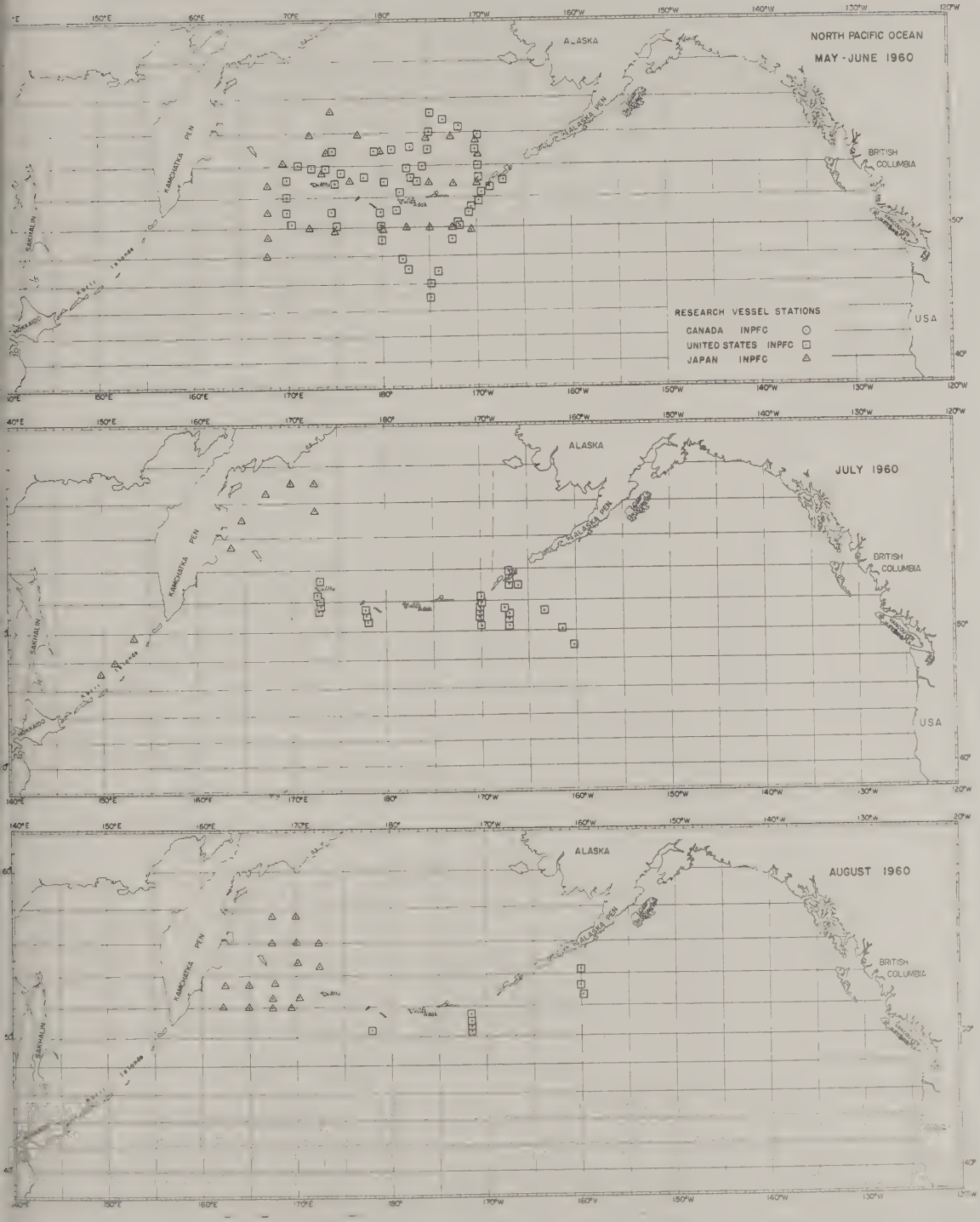
Appendix Figure A-3. 1957.



Appendix Figure A-4. 1958.



Appendix Figure A-5. 1959.



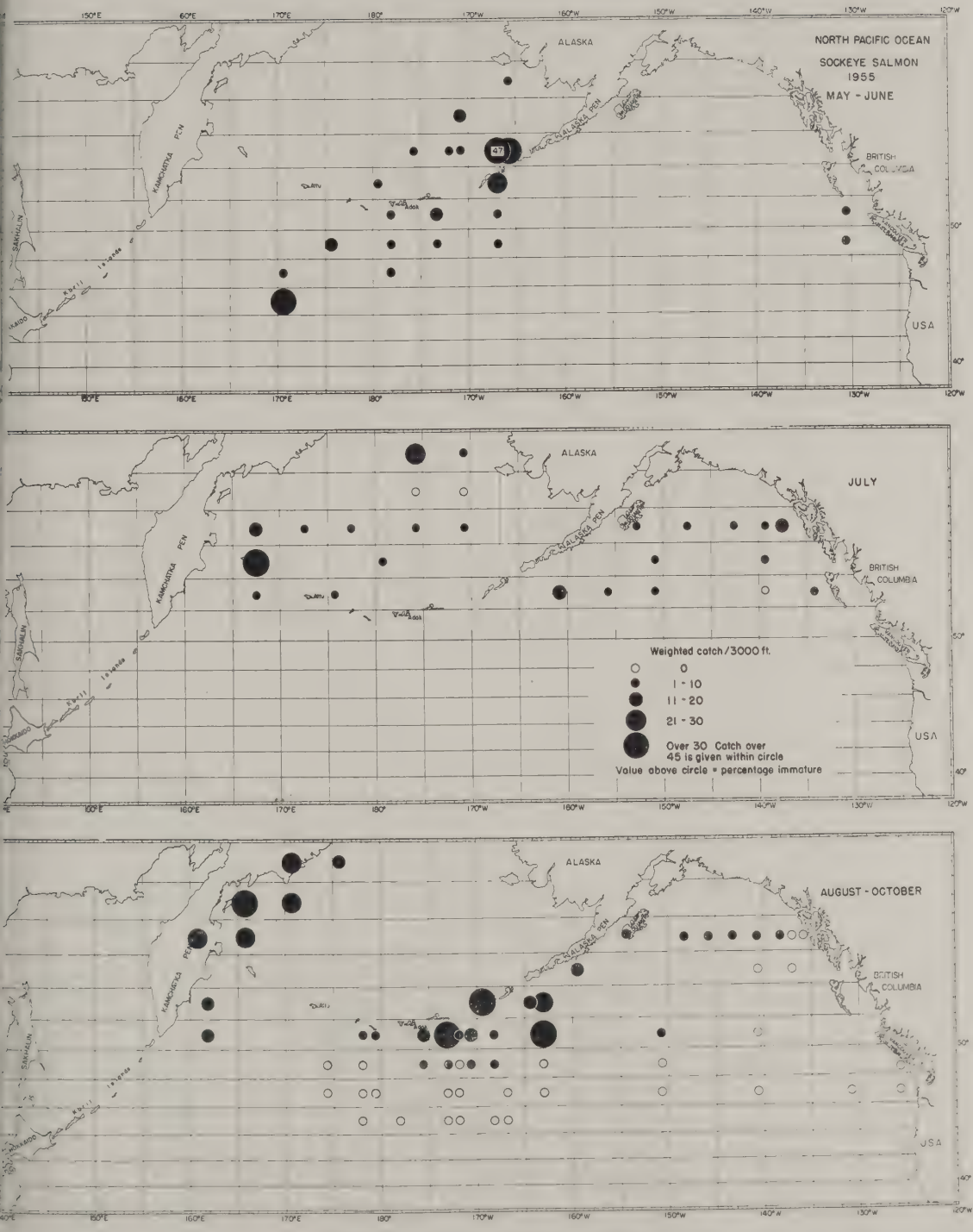
Appendix Figure A-6. 1960.

APPENDIX FIGURE B. RELATIVE ABUNDANCE (CATCH PER 3,000 FEET OF GILLNET, EACH MESH SIZE GIVEN EQUAL WEIGHT) OF SOCKEYE, CHUM, PINK, COHO AND CHINOOK SALMON, 1955–1960

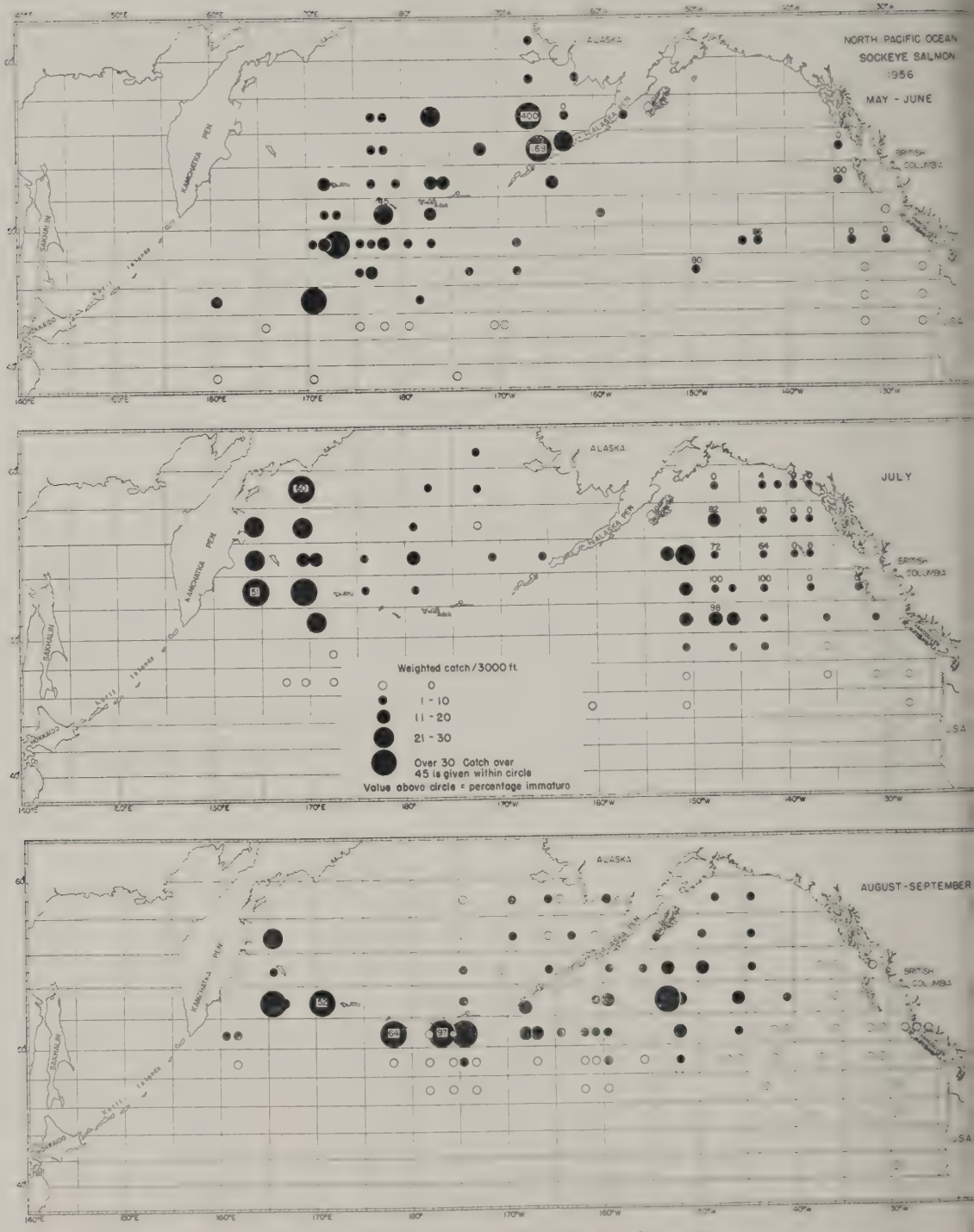
(Values for each species but chinook are shown for May; early, mid and late 10-day periods of June, July and August; and for September. The period of fishing is indicated by the position of the symbol within each $2° \times 5°$ rectangle, i.e., from left to right, May, early June, mid-June and late June, etc. Values for chinook are shown on a monthly basis. For sockeye and chum salmon, the percentage (weighted) of immature individuals in the catch is shown for some years by numerals above the relative abundance symbols.)

Page

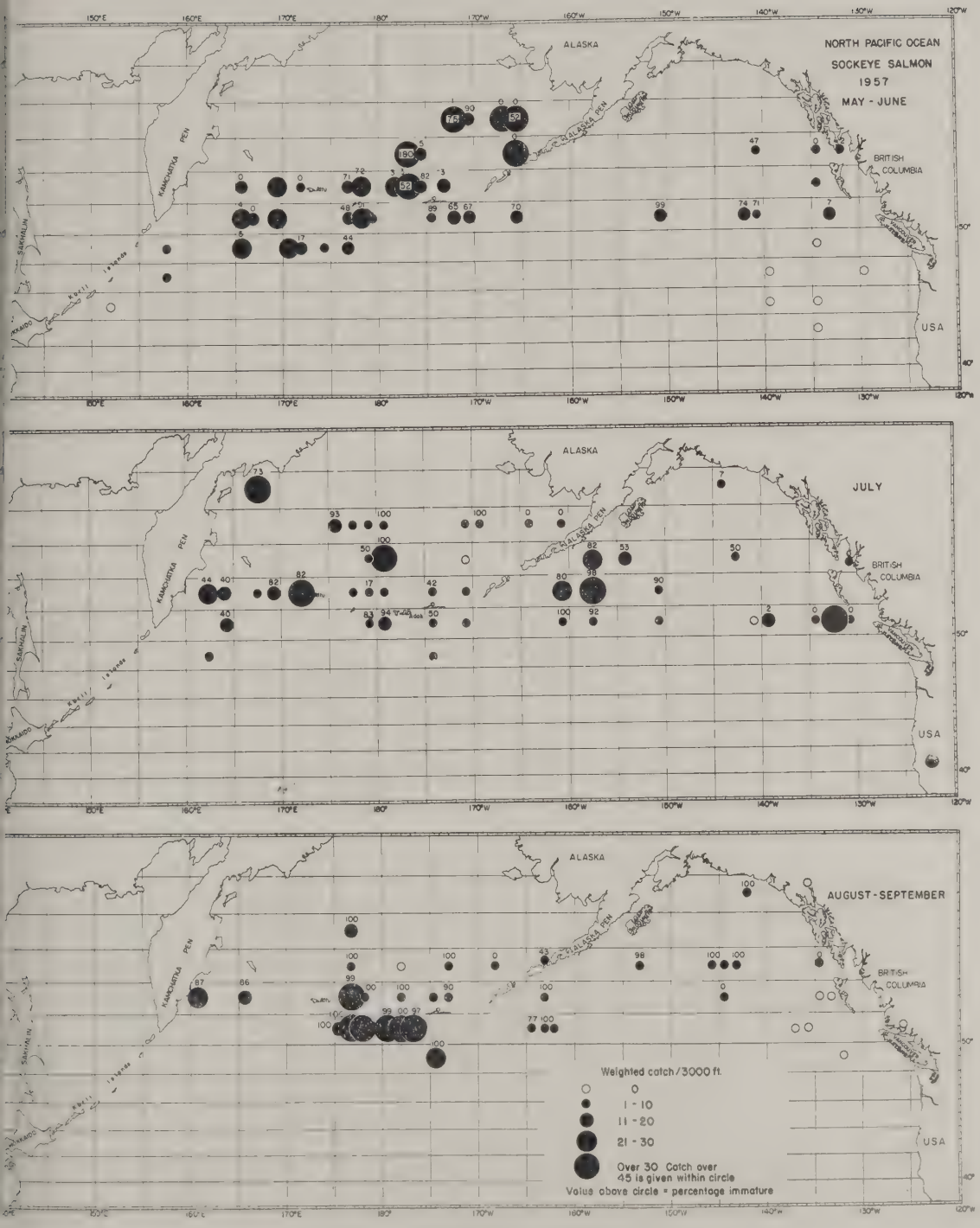
B-1. Sockeye 375
B-2. Chum 381
B-3. Pink 387
B-4. Coho 393
B-5. Chinook 399



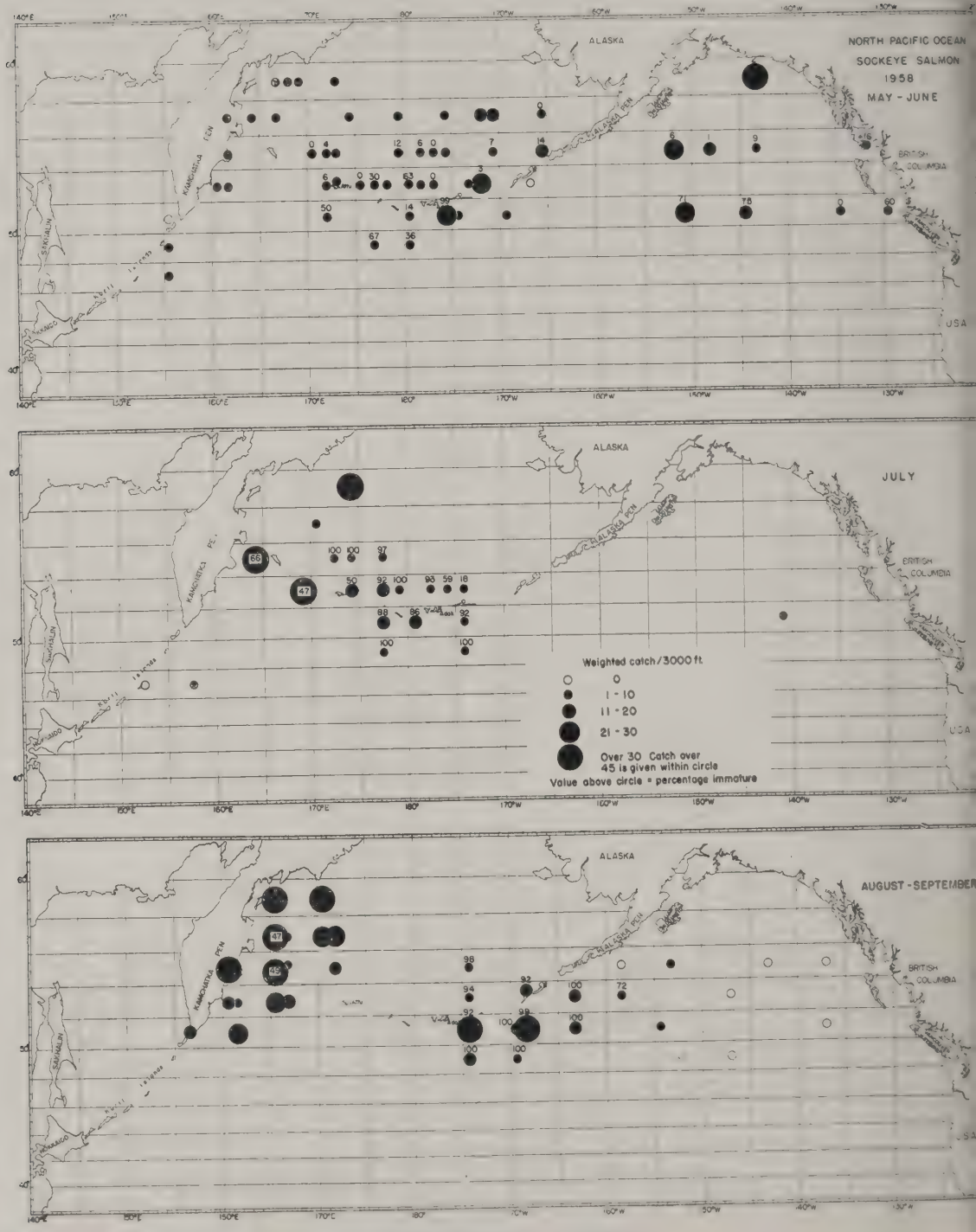
Appendix Figure B-1. Sockeye, 1955–1960.



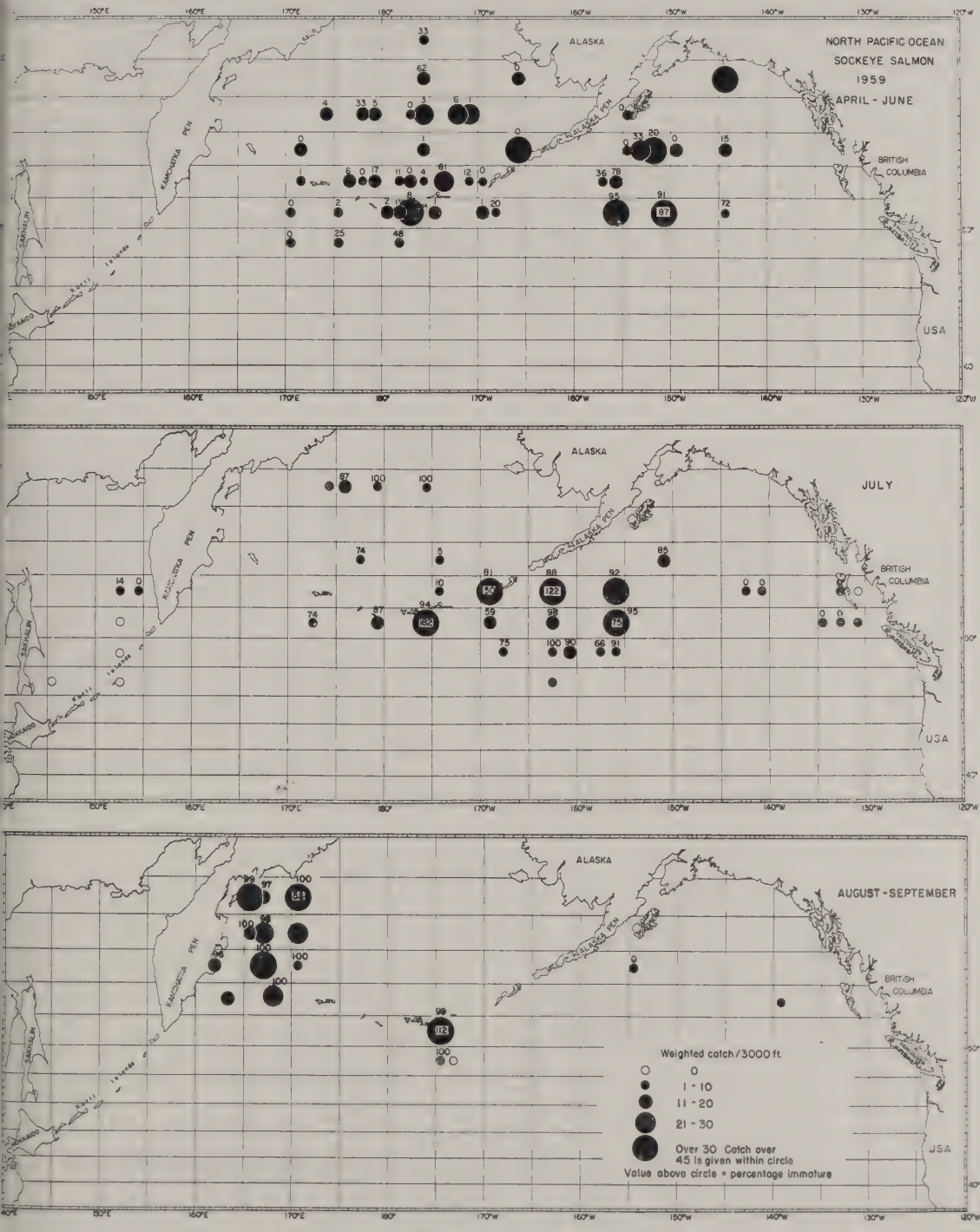
Appendix Figure B-1. Continued.



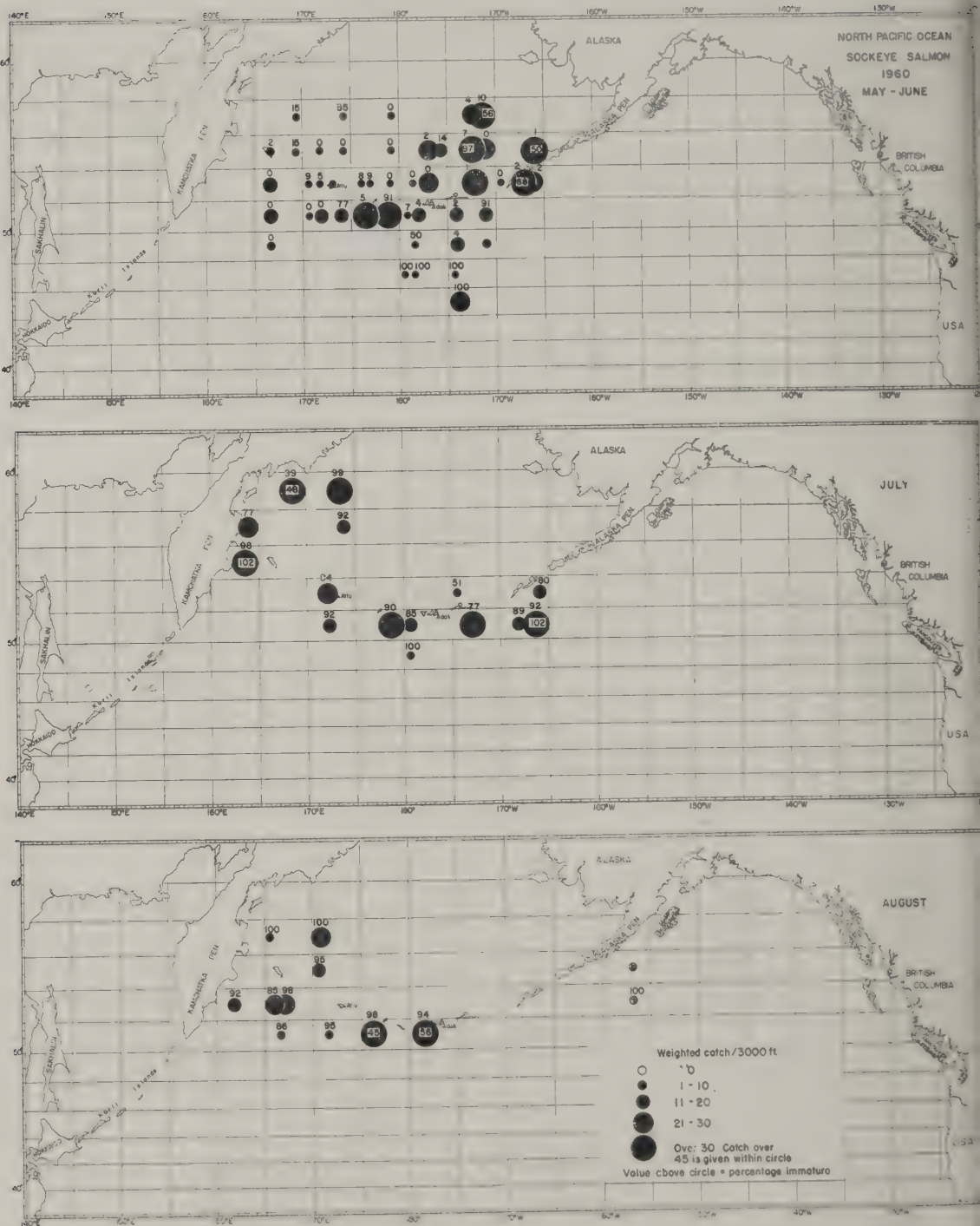
Appendix Figure B-1. Continued.



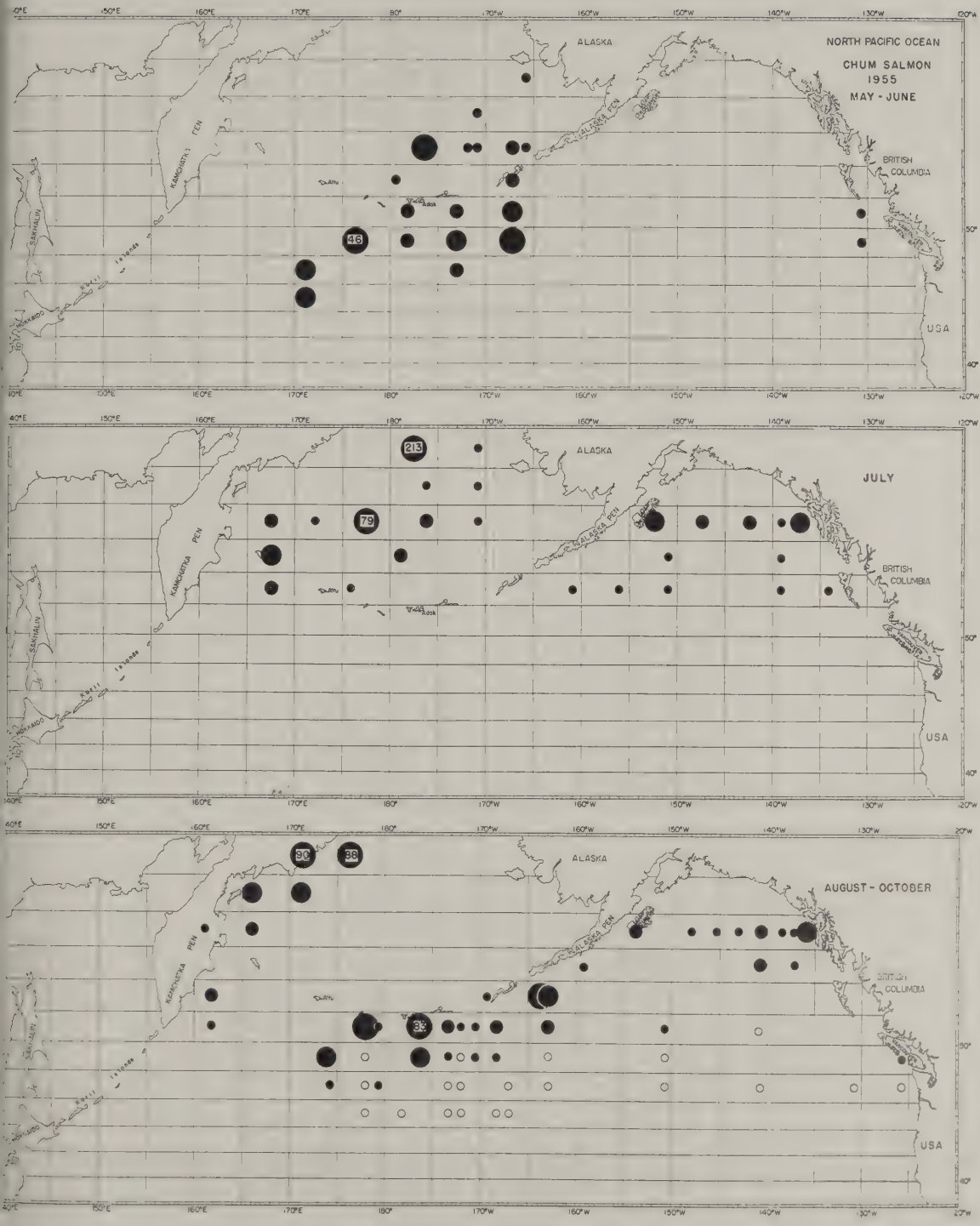
Appendix Figure B-1. Continued.



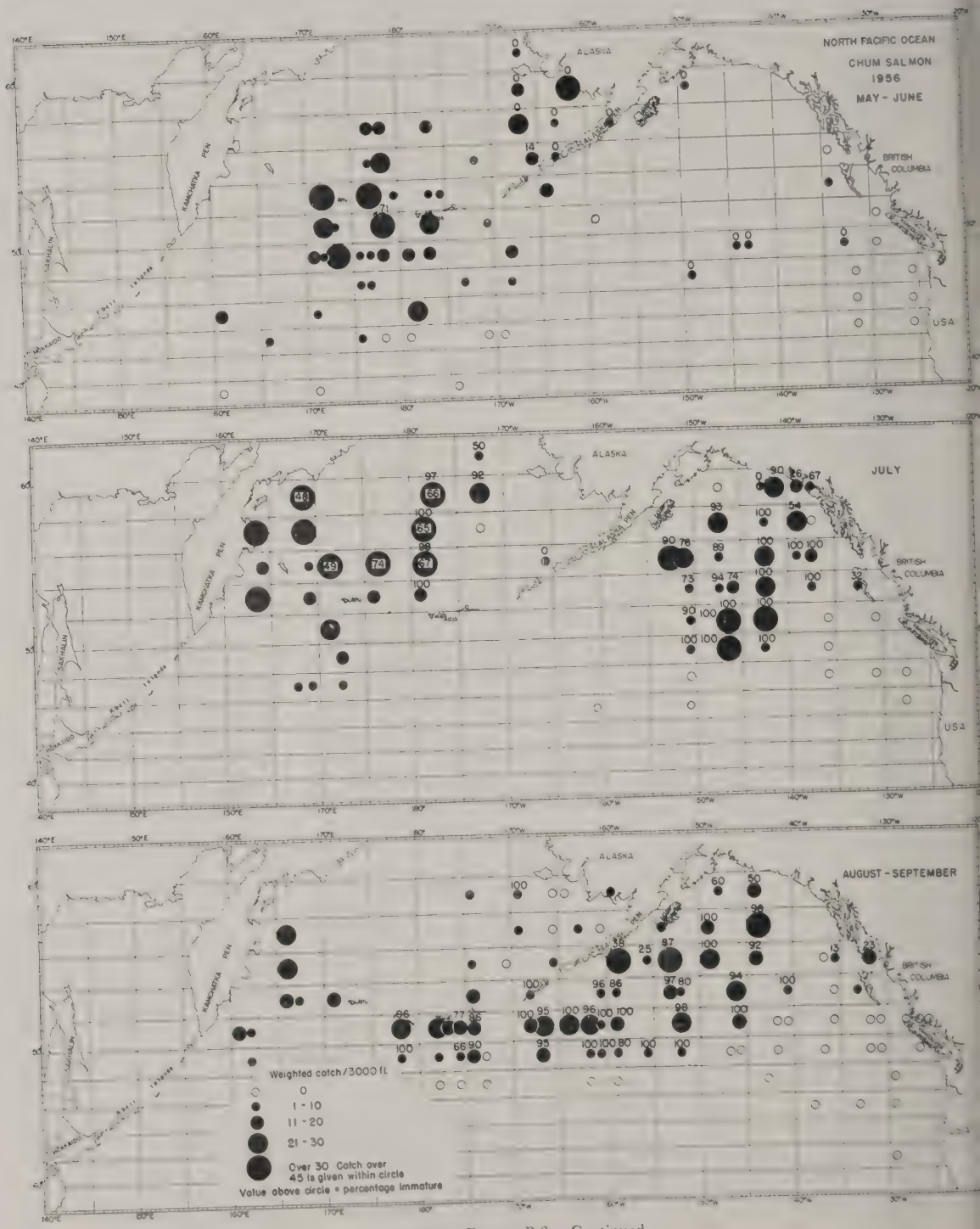
Appendix Figure B-1. Continued.

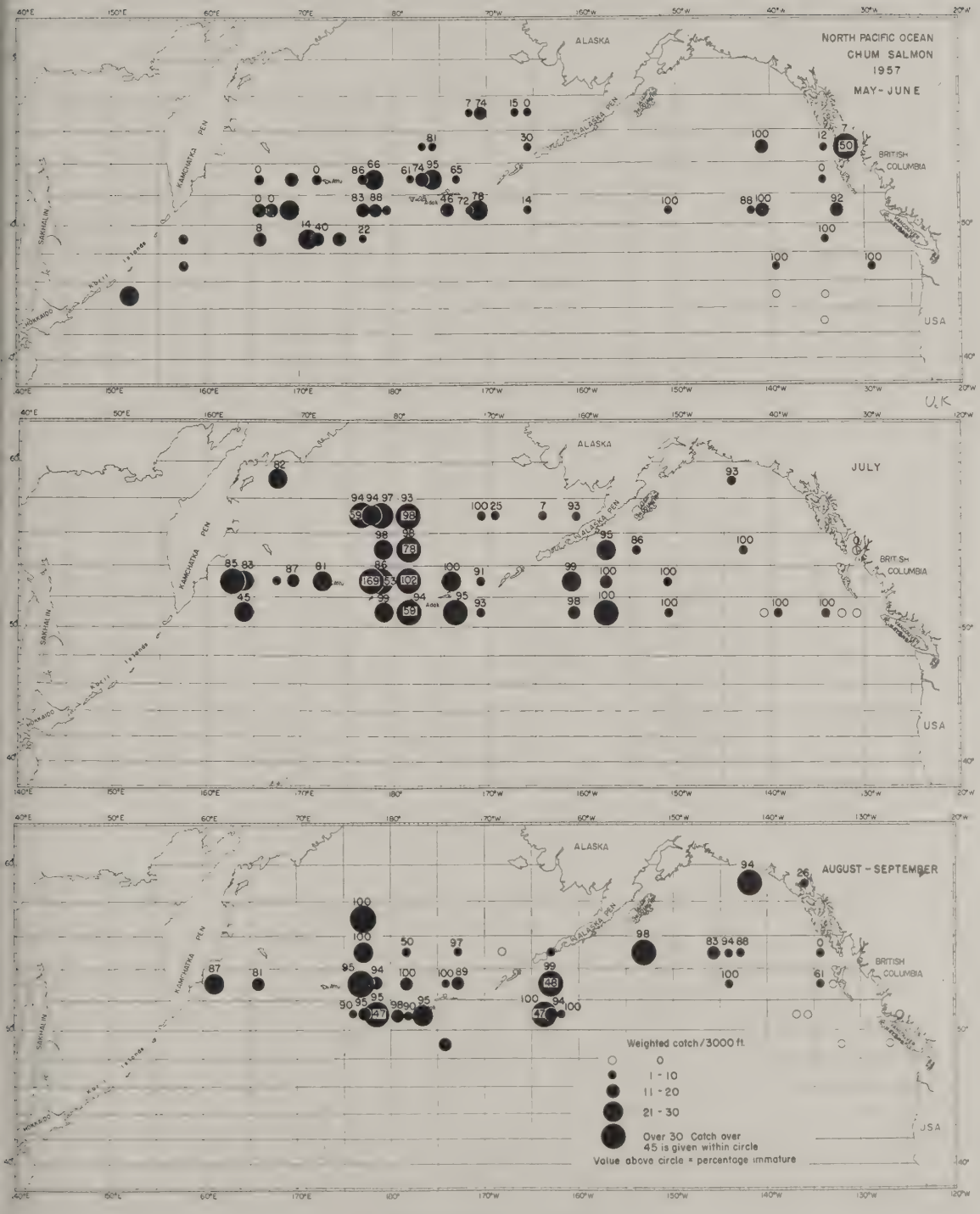


Appendix Figure B-1. Continued.

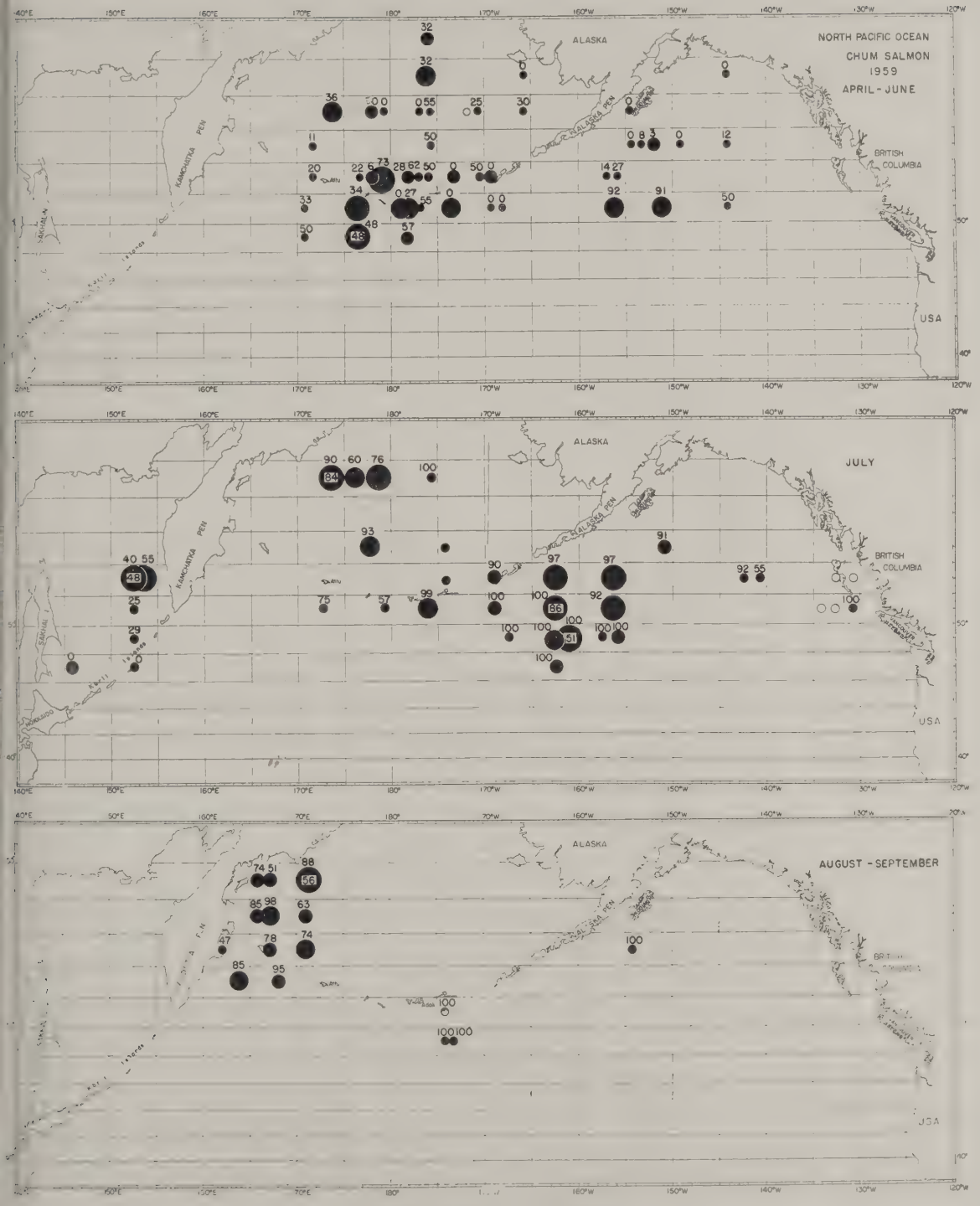


Appendix Figure B-2. Chum, 1955–1960.

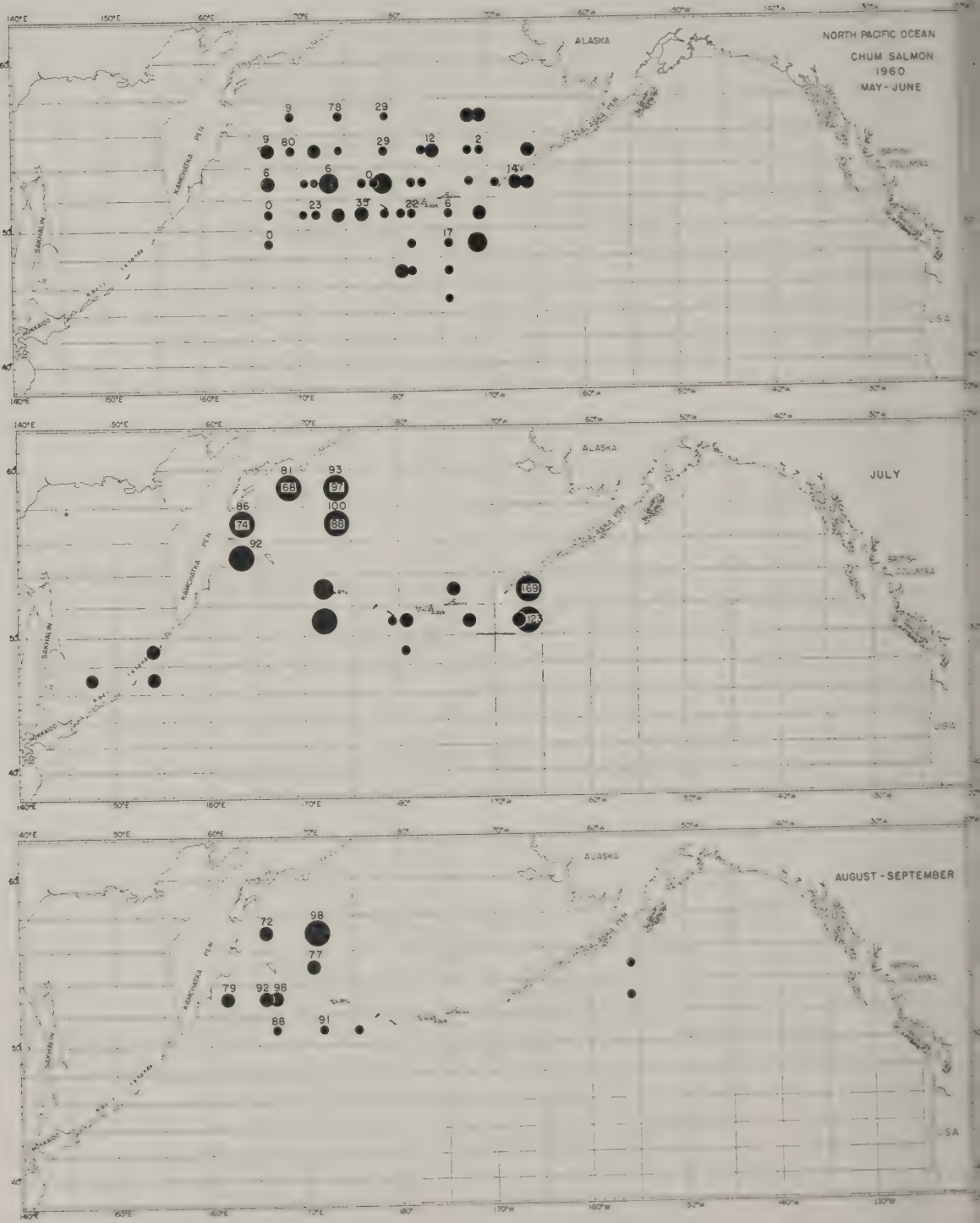


APPENDIX FIGURE B-2. Continued.

APPENDIX FIGURE B-2. - Continued.

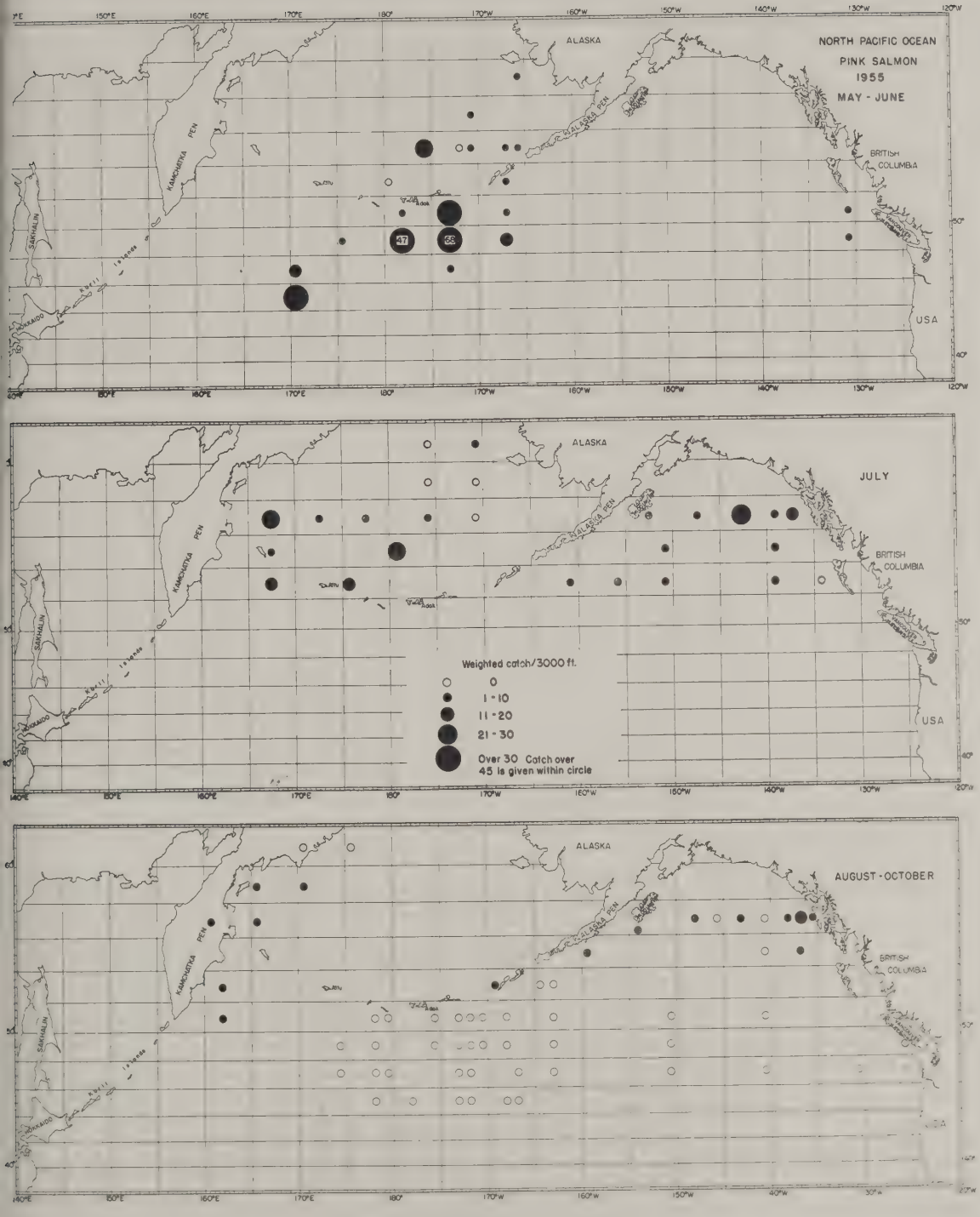
Appendix Figure B-2. Continued.



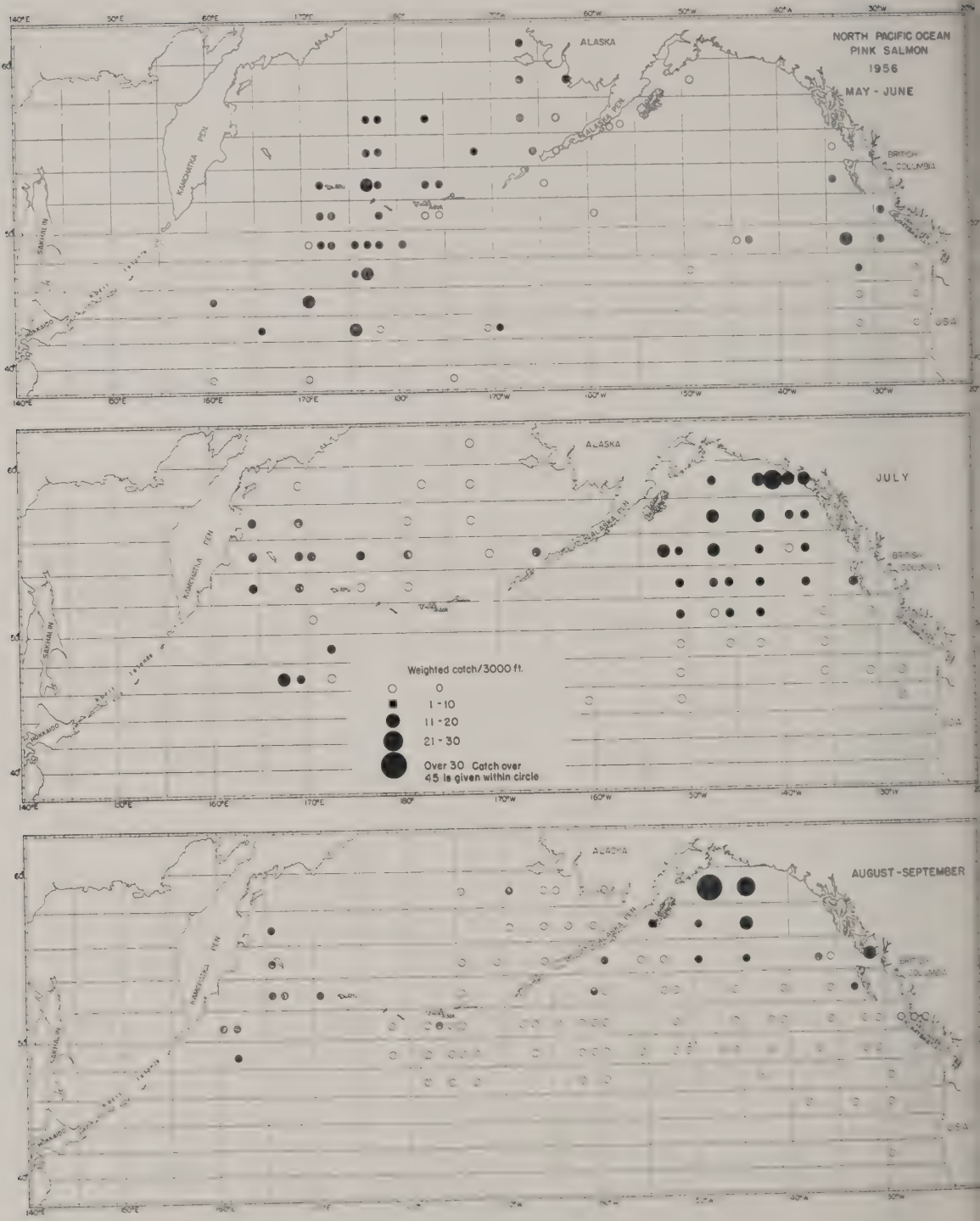
Appendix Figure B-2. Continued.



Appendix Figure B-2. Continued.



Appendix Figure B-3. Pink, 1955 1960.



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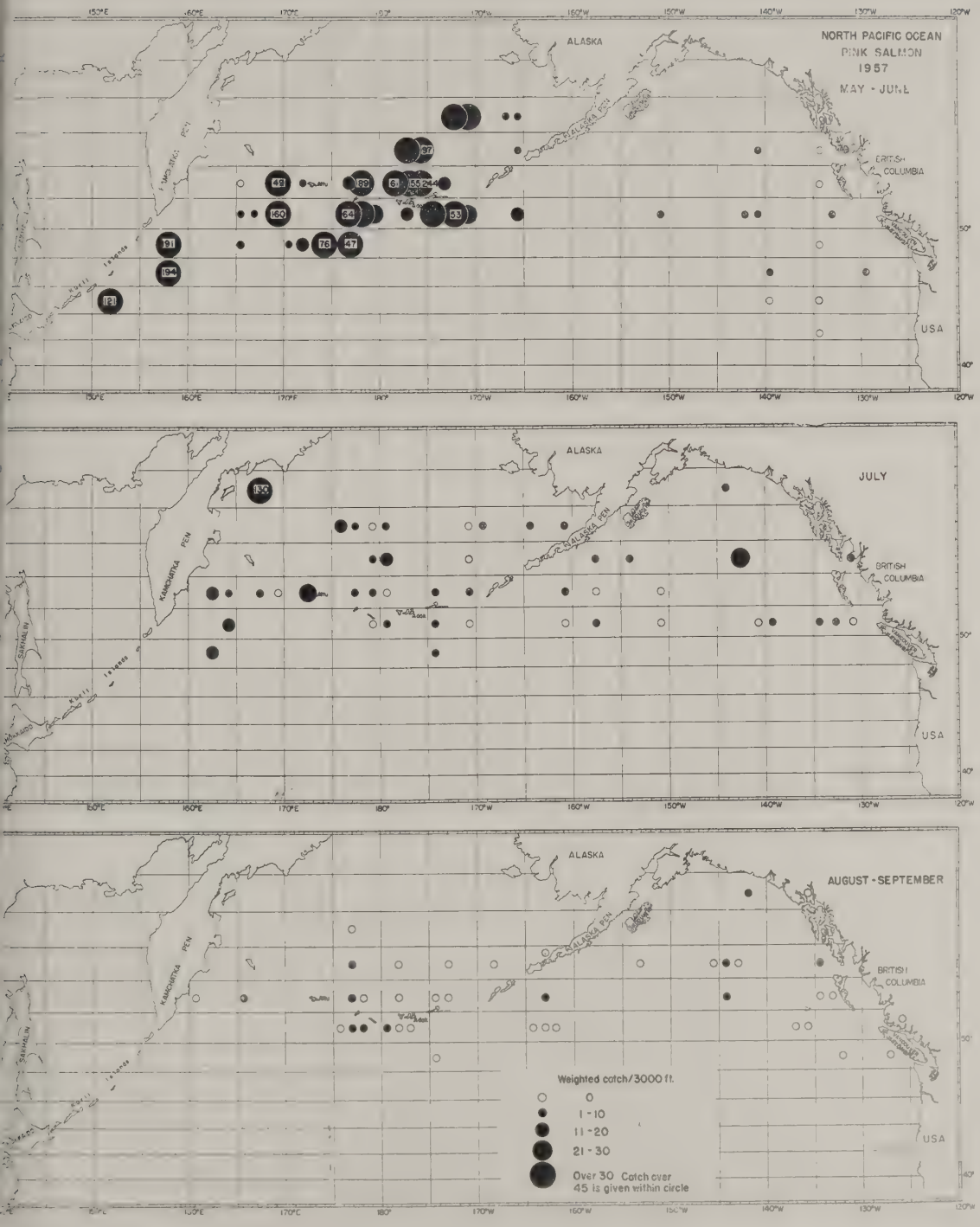
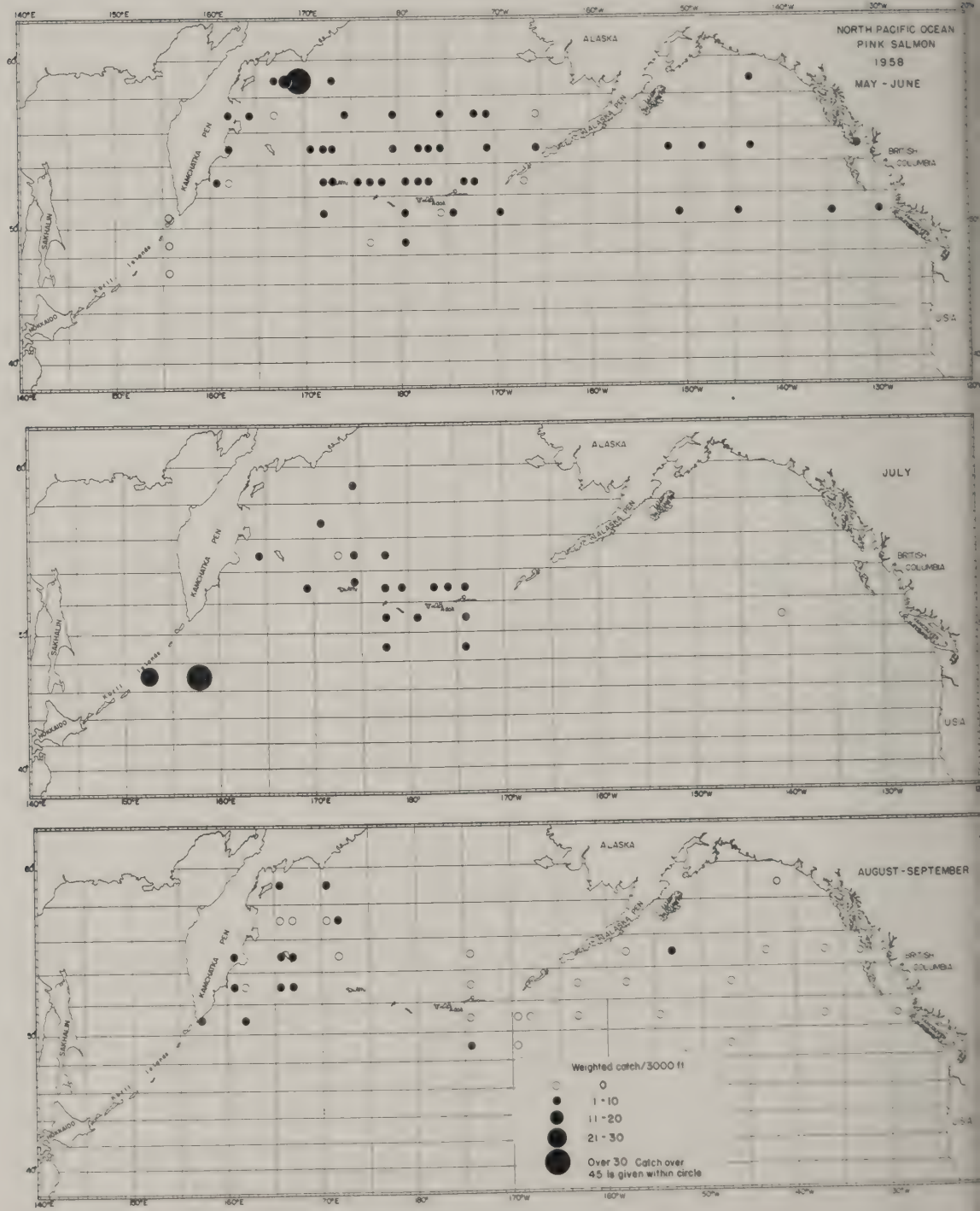
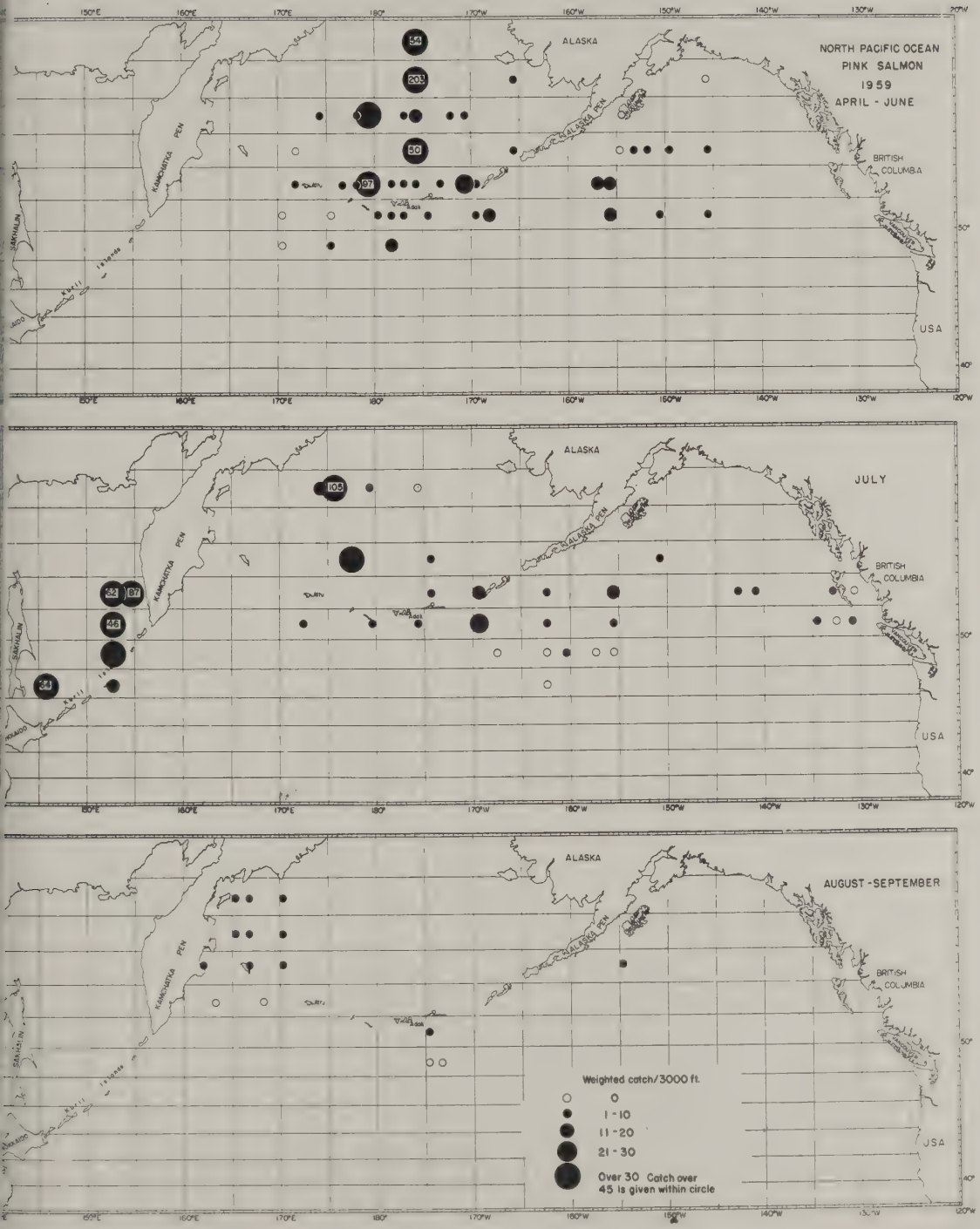


Appendix Figure B-3. Continued.



Appendix Figure B-3. Continued.



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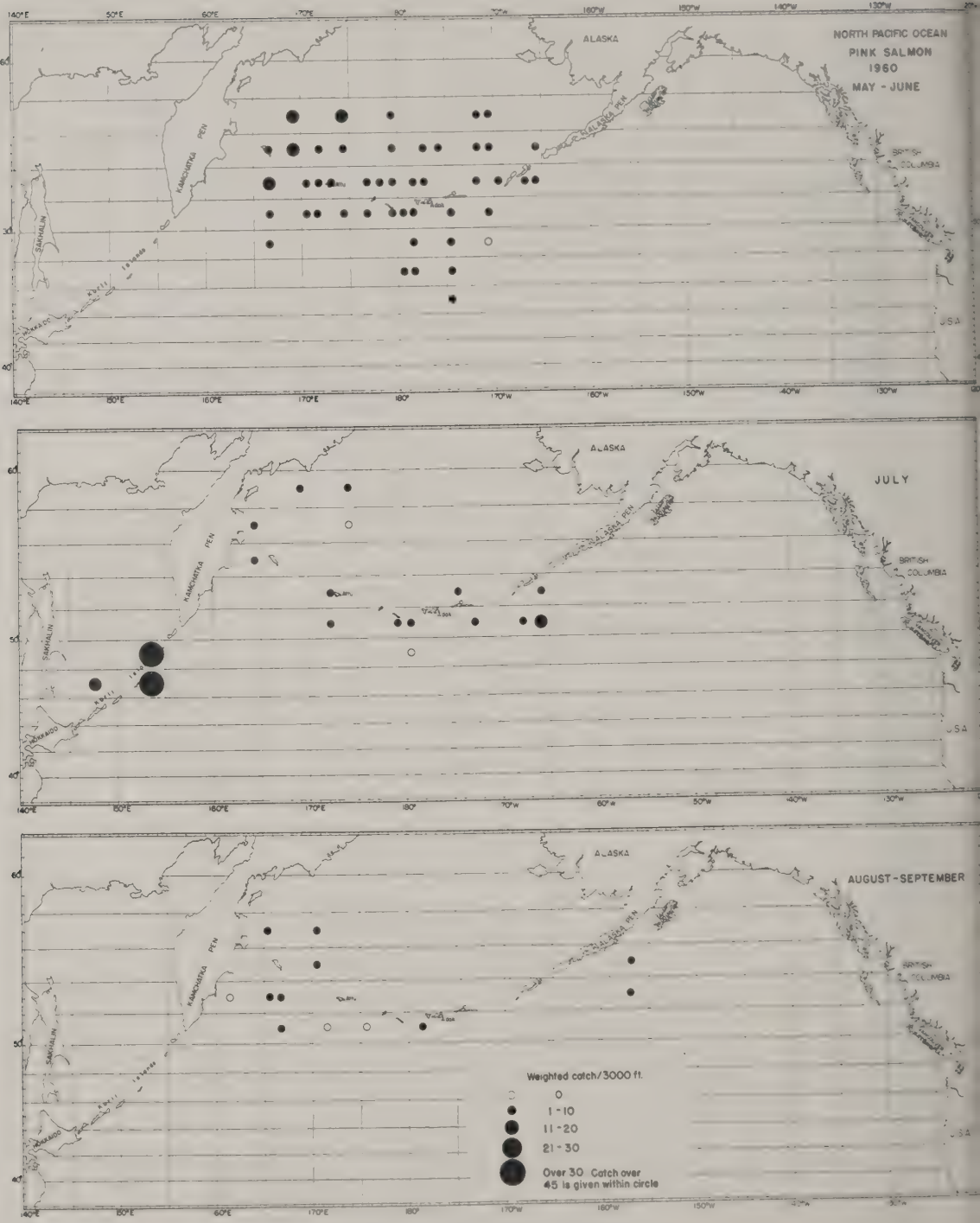

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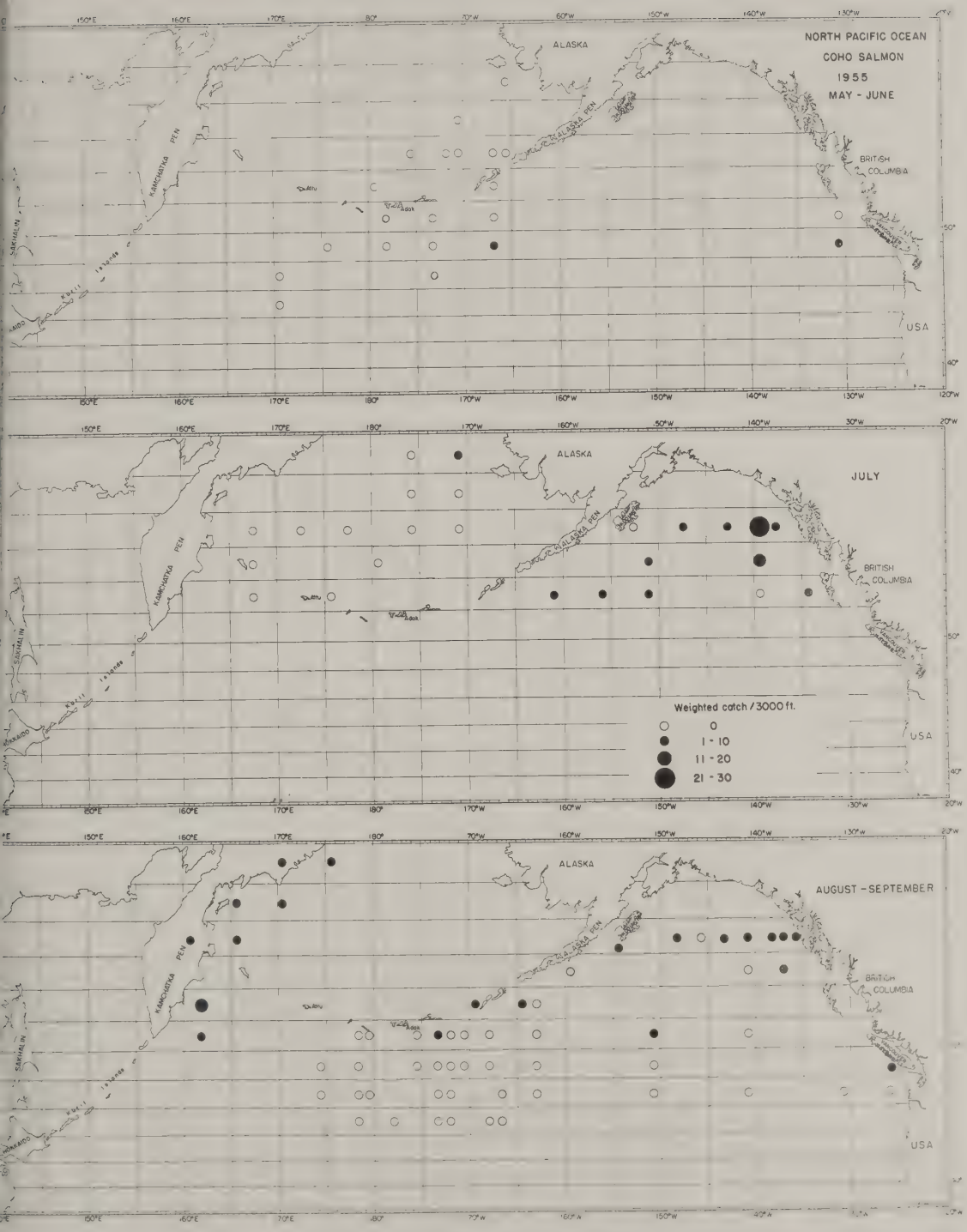
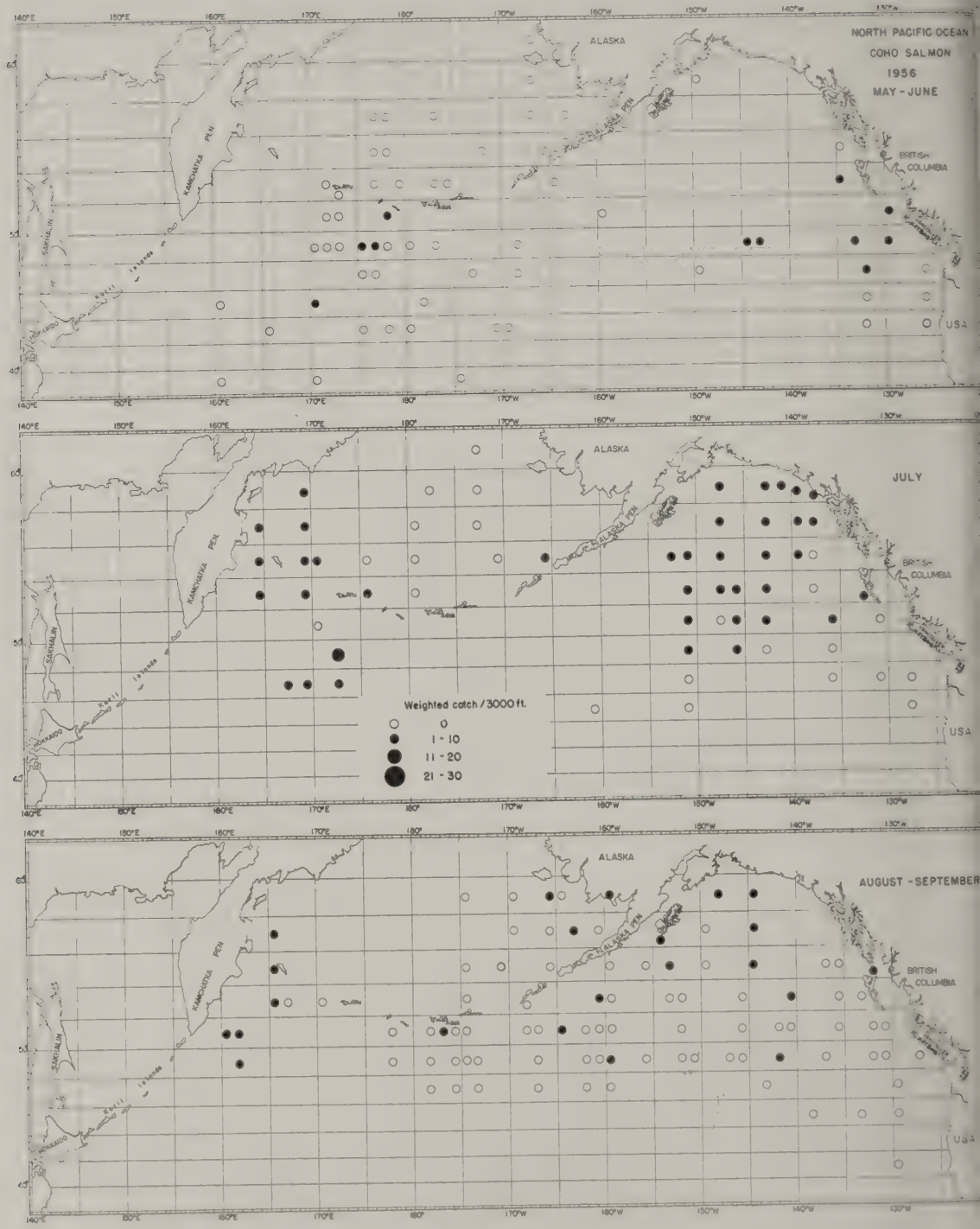


Appendix Figure B-4. Coho, 1955–1960.



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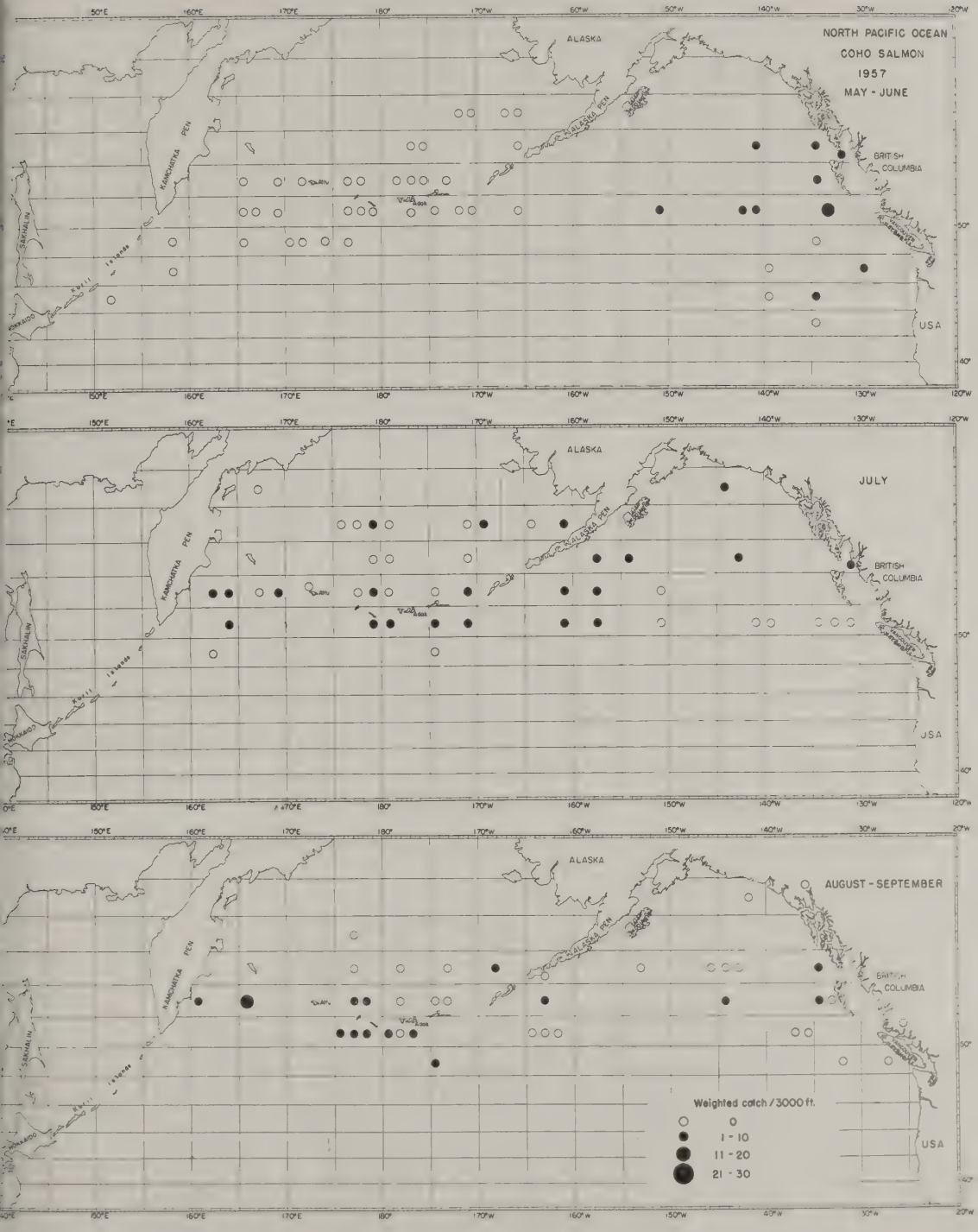

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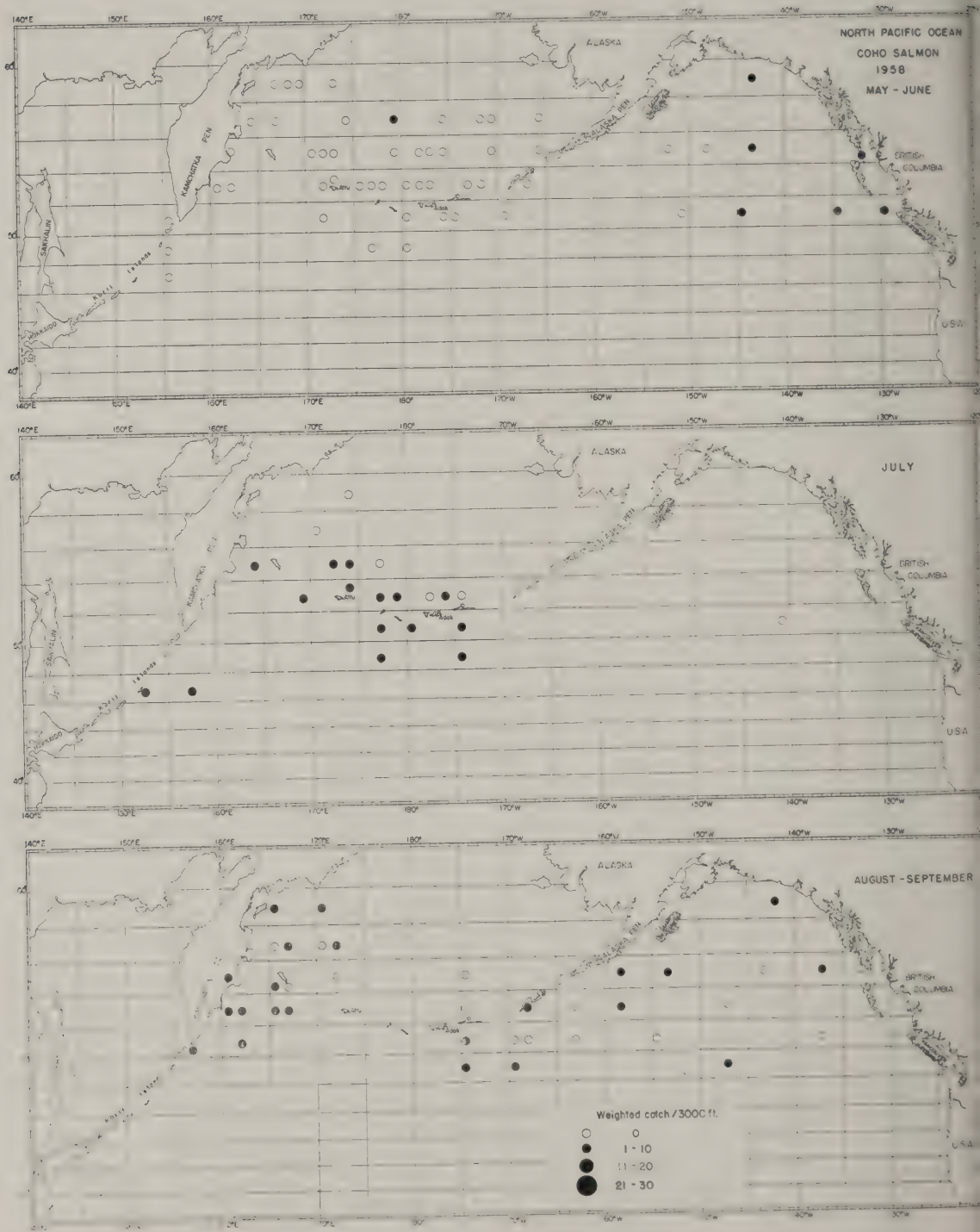

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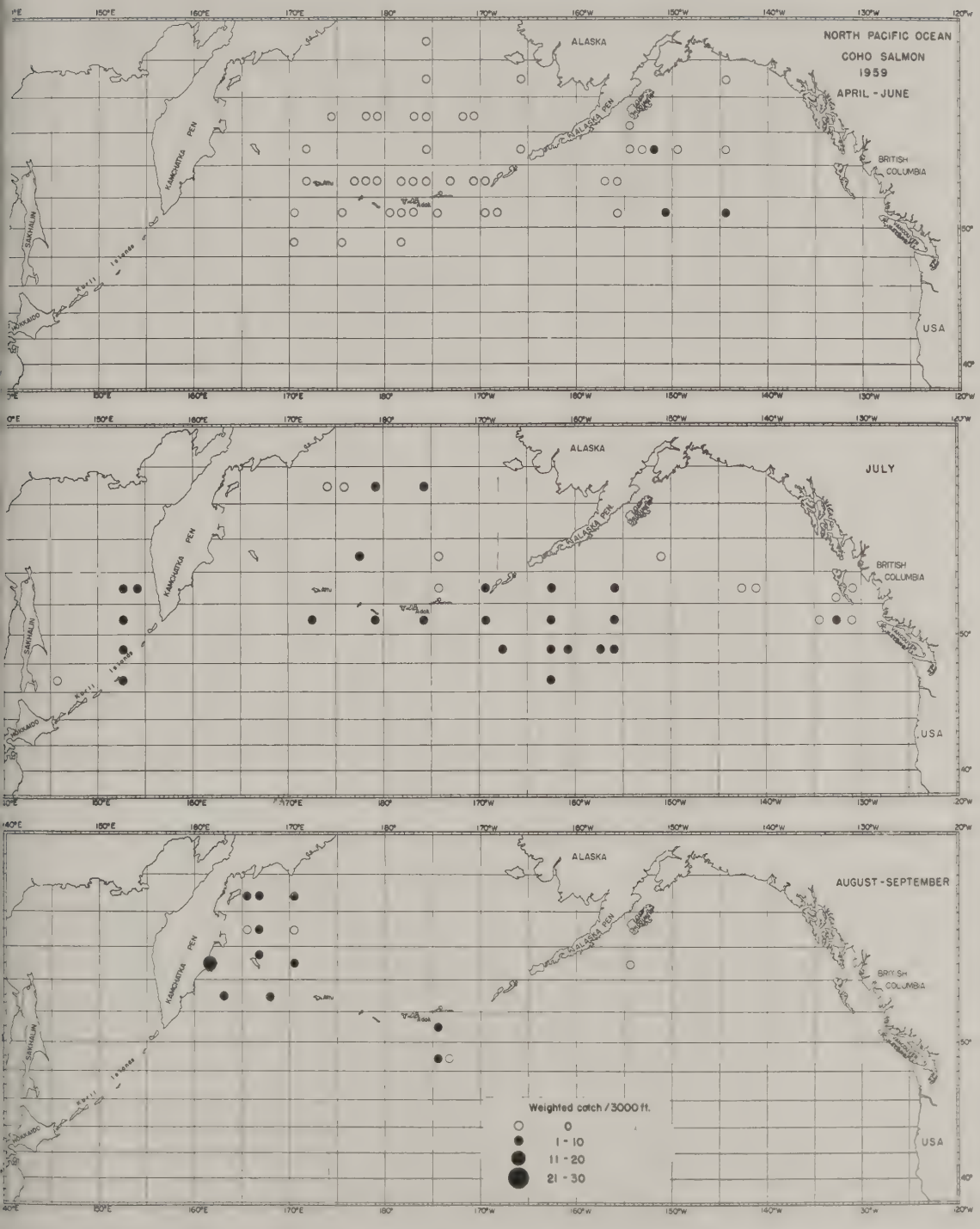

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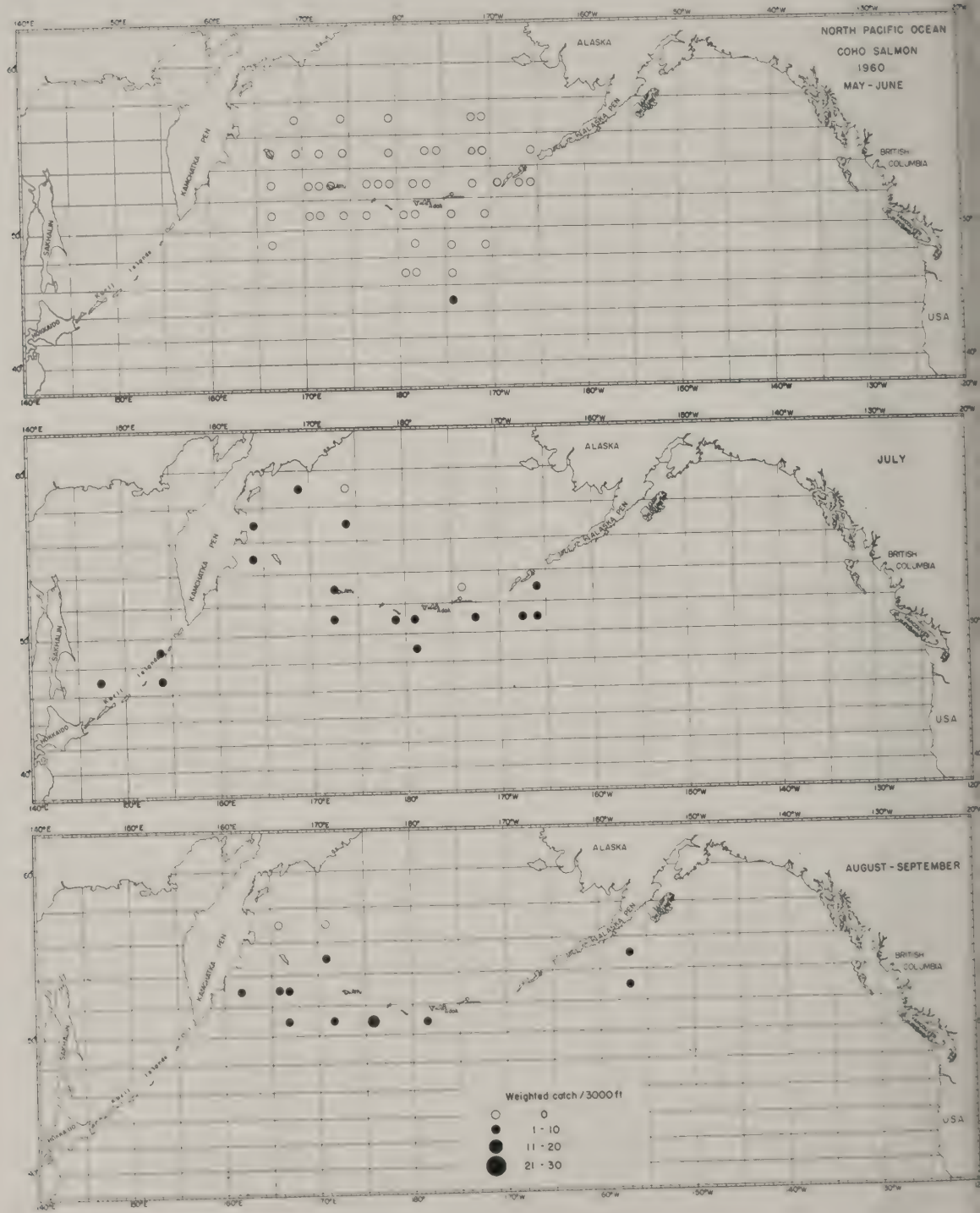

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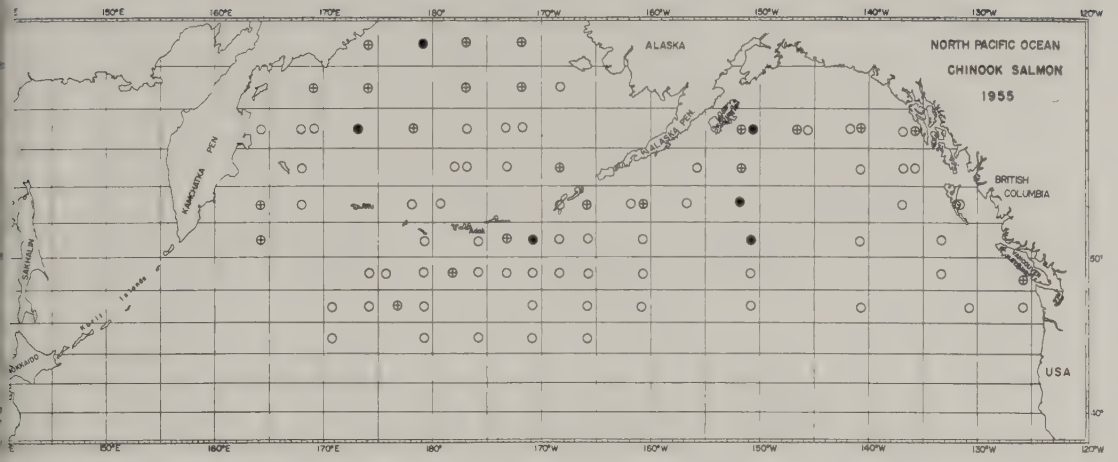
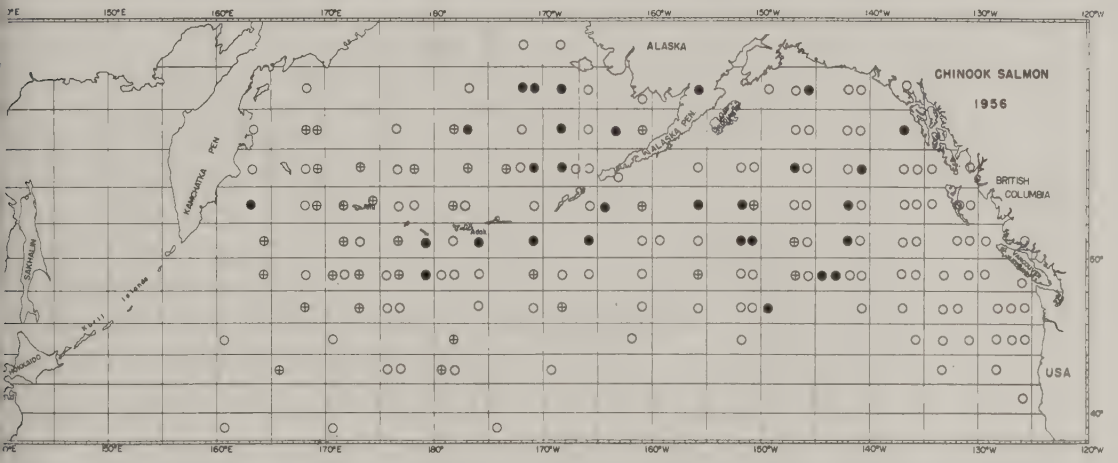
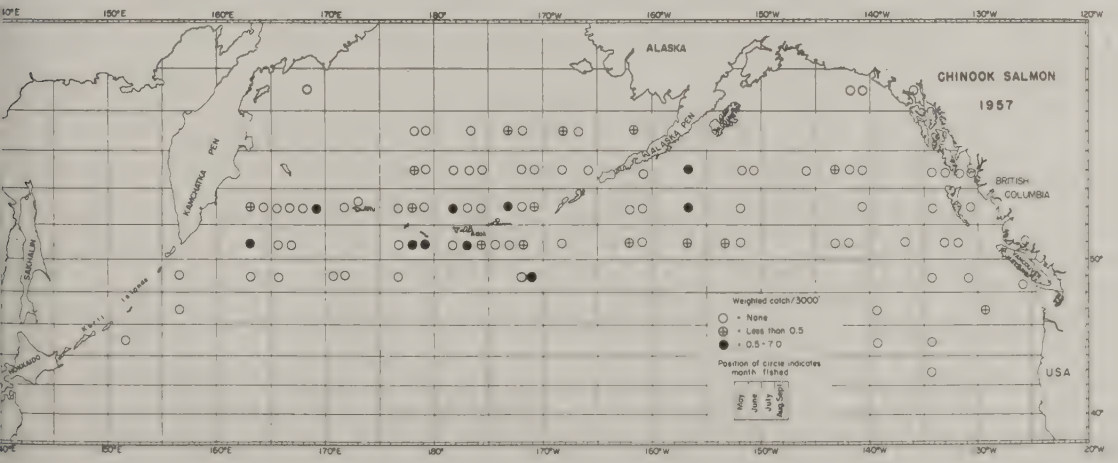
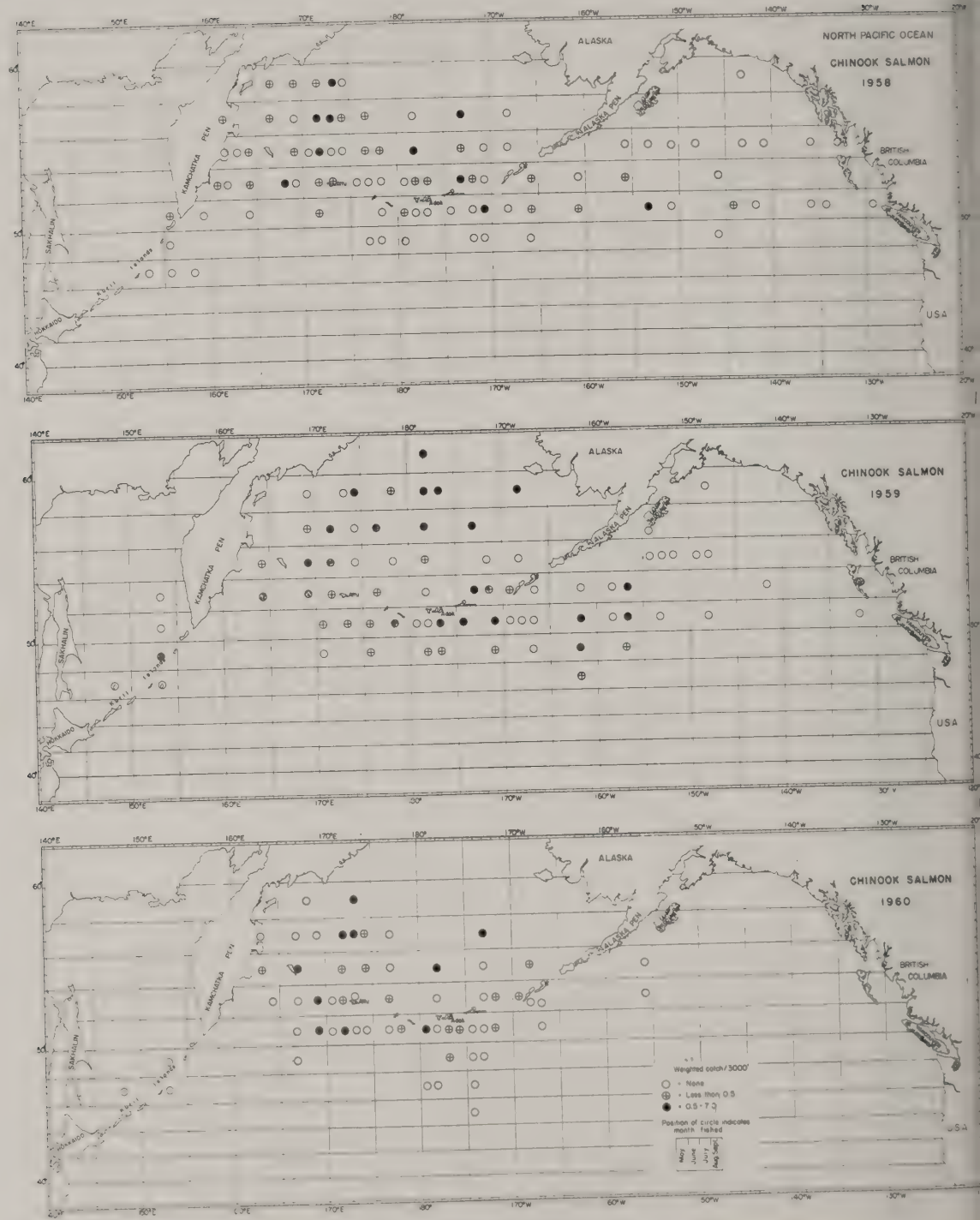






Appendix Figure B-5. Chinook, 1955–1960.



Appendix Figure B-5. Continued.

APPENDIX FIGURE C. MOTHERSHIP CATCHES OF SOCKEYE, CHUM, PINK, COHO AND CHINOOK SALMON BY EARLY, MID AND LATE 10-DAY PERIODS WITHIN STATISTICAL AREAS, AND BY FIVE DEGREE INTERVALS OF LONGITUDE (SHOWN ALONG THE BASE OF THE FIGURE), 1952–1960

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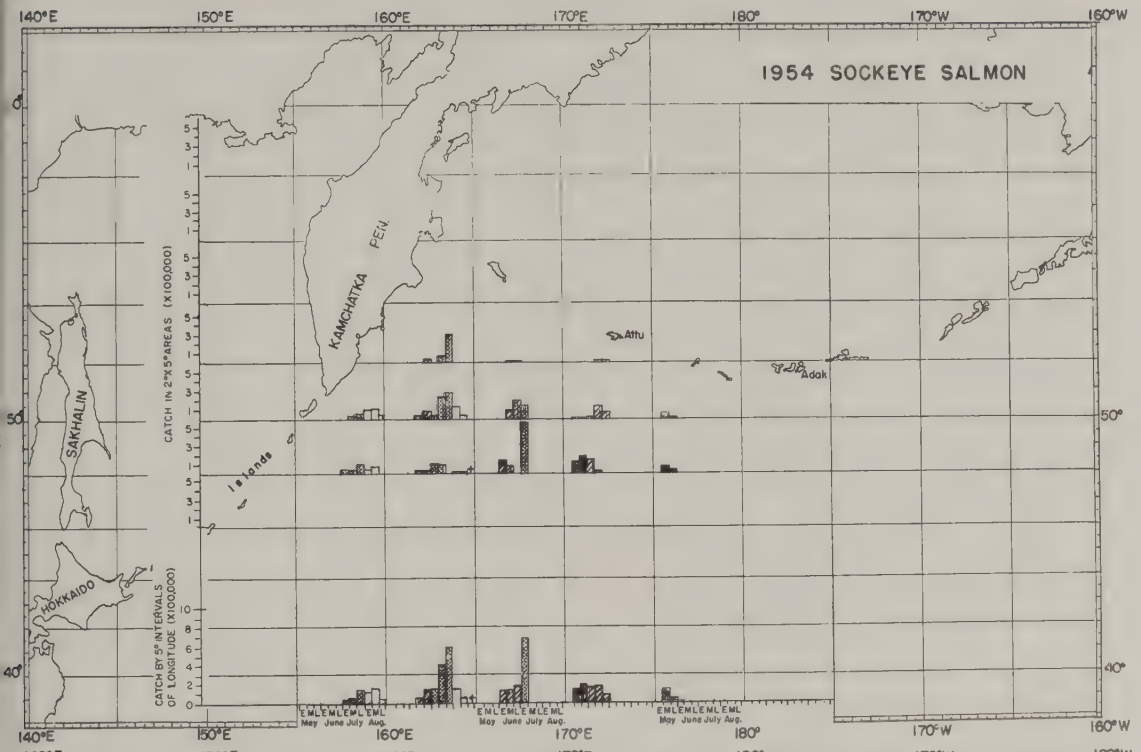
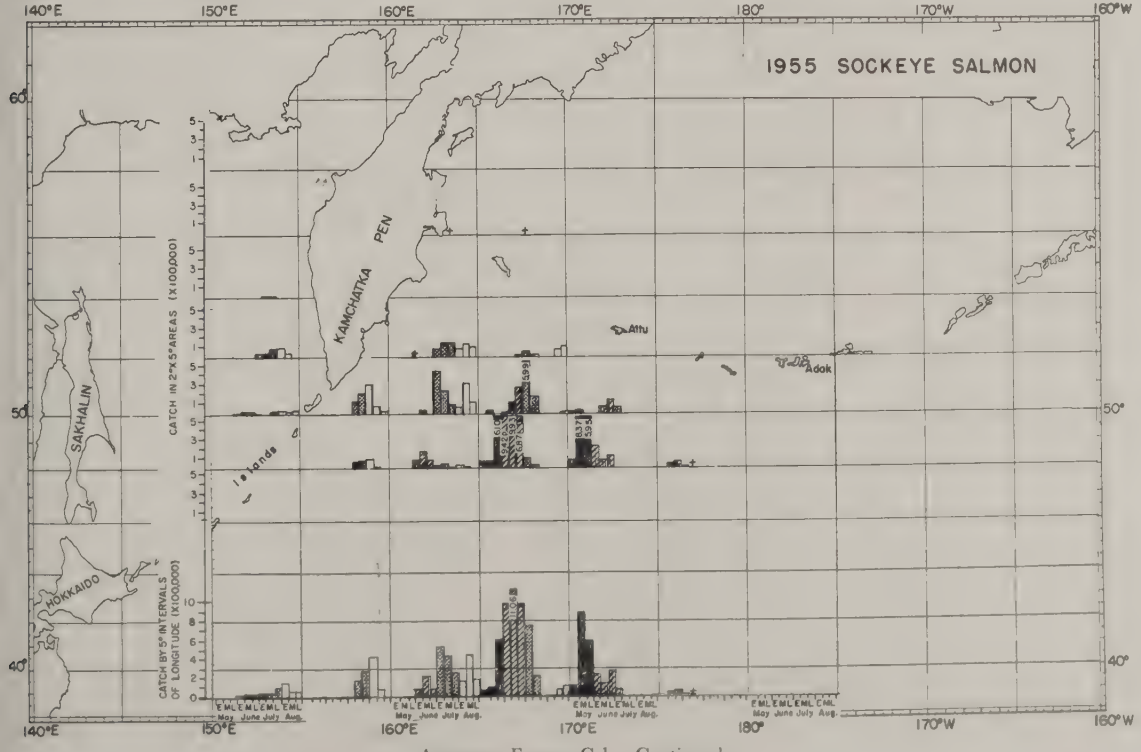
C-1. Sockeye 402
C-2. Chum 407
C-3. Pink 412
C-4. Coho 417
C-5. Chinook 422

Appendix Figure C-1. Sockeye, 1952–1960.





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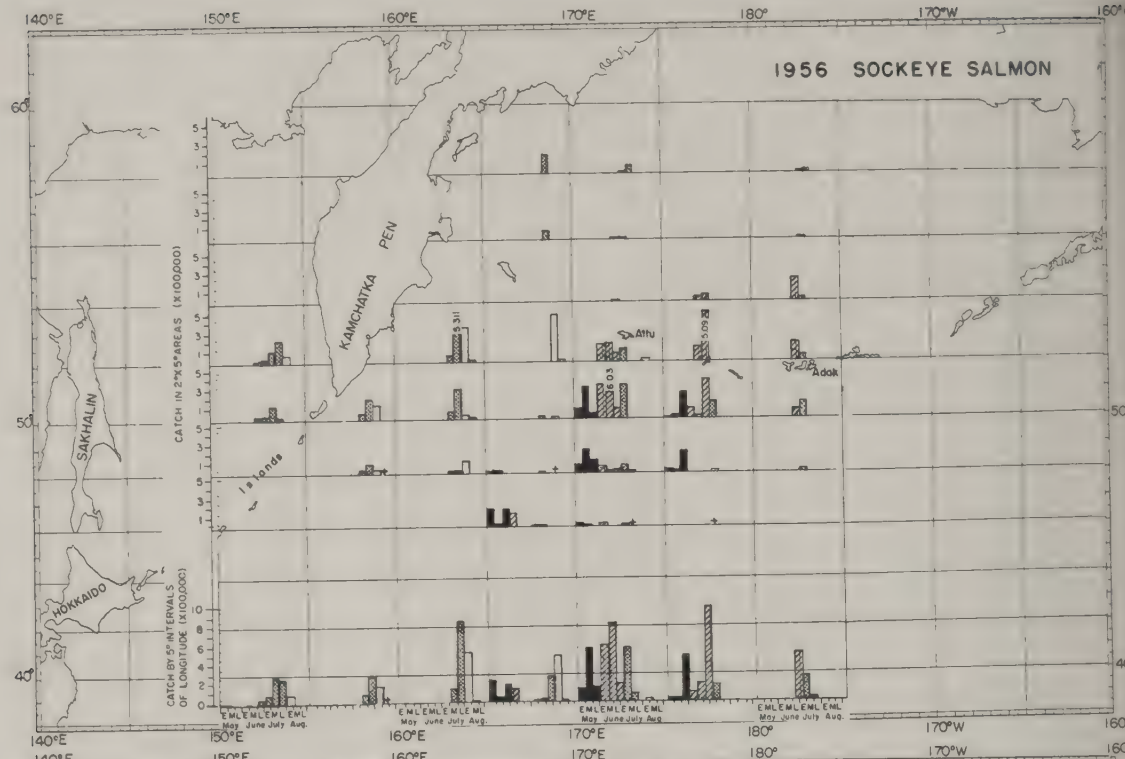

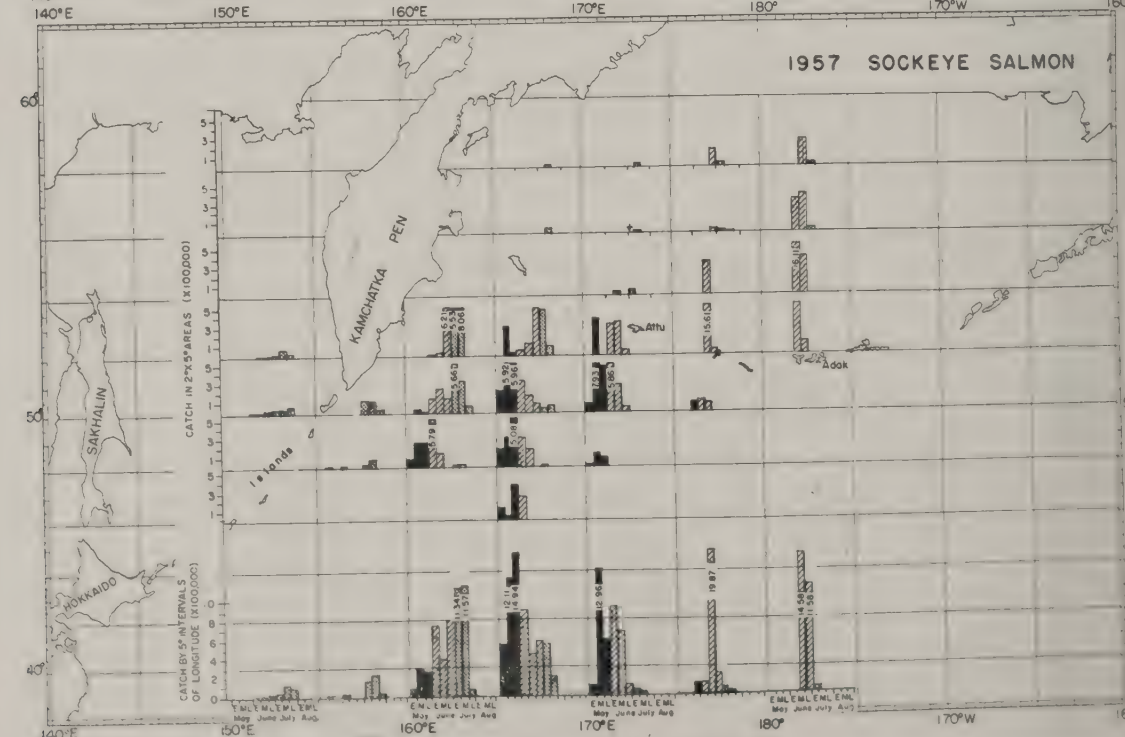

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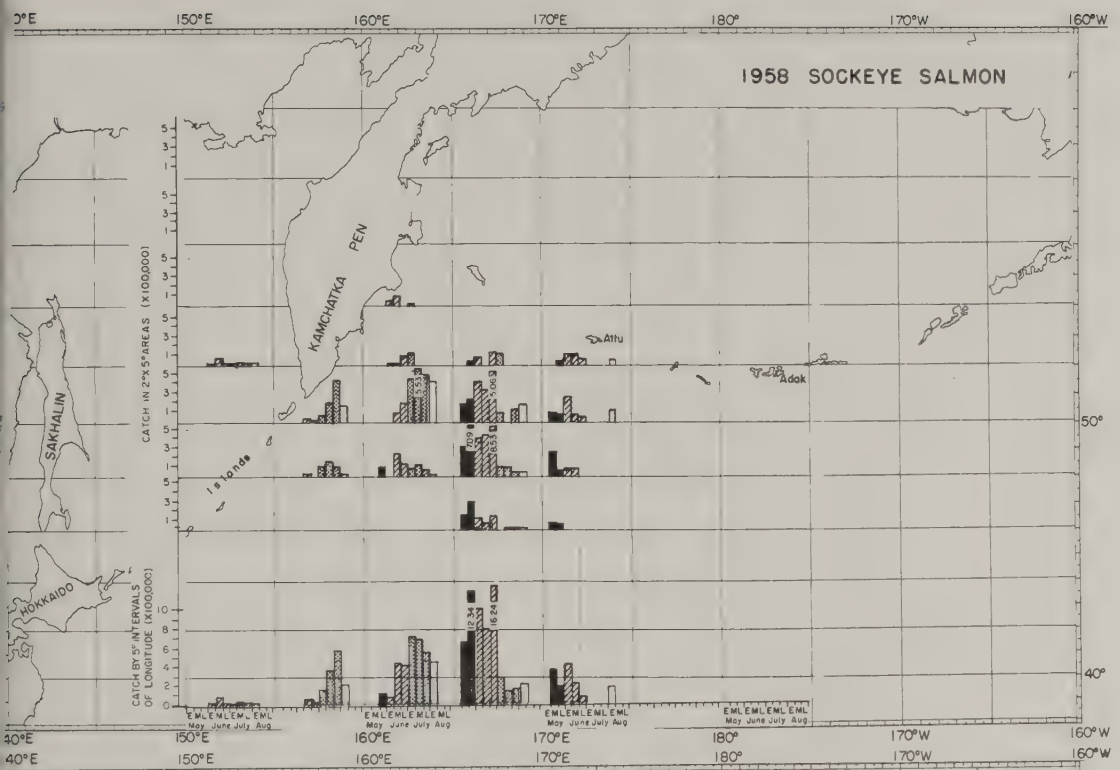
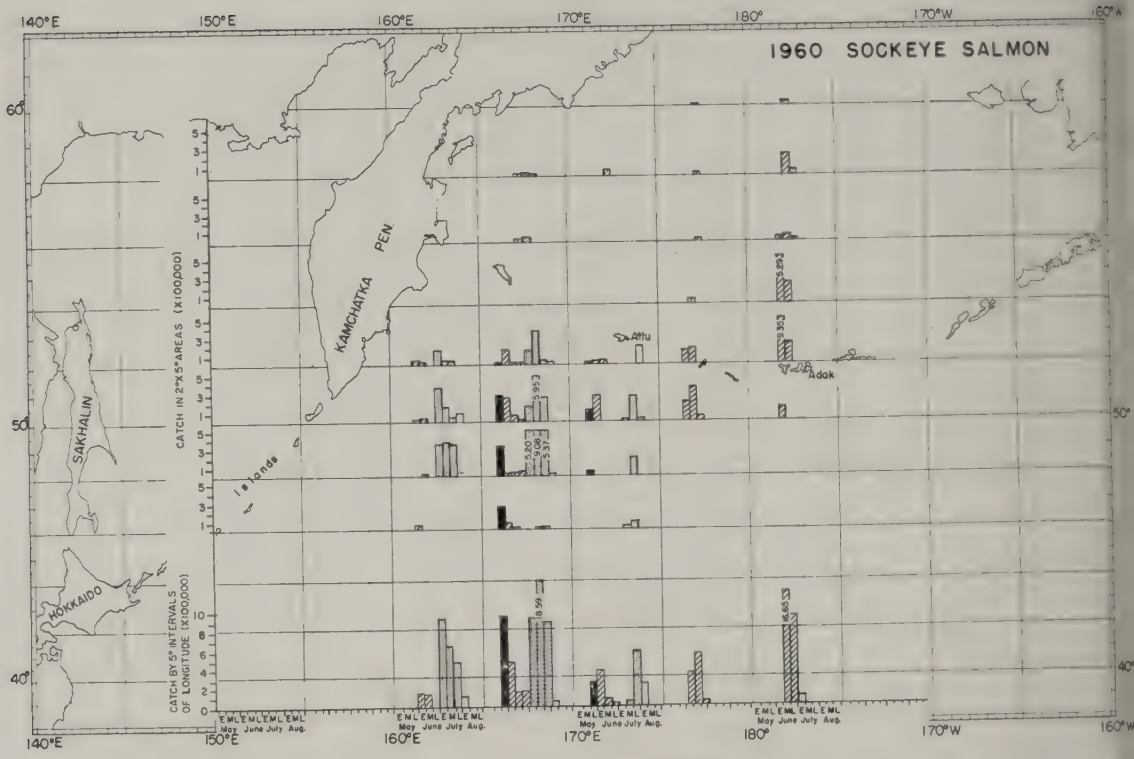

1958 SOCKEYE SALMON
KAMCHATKA PEN
SAKHALIN
HOKKAIDO
Attu
Adak
Islands
CATCH IN 2°X5° AREAS (X100,000)
CATCH BY 5° INTERVALS OF LONGITUDE (X100,000)
E M L E M L E M L



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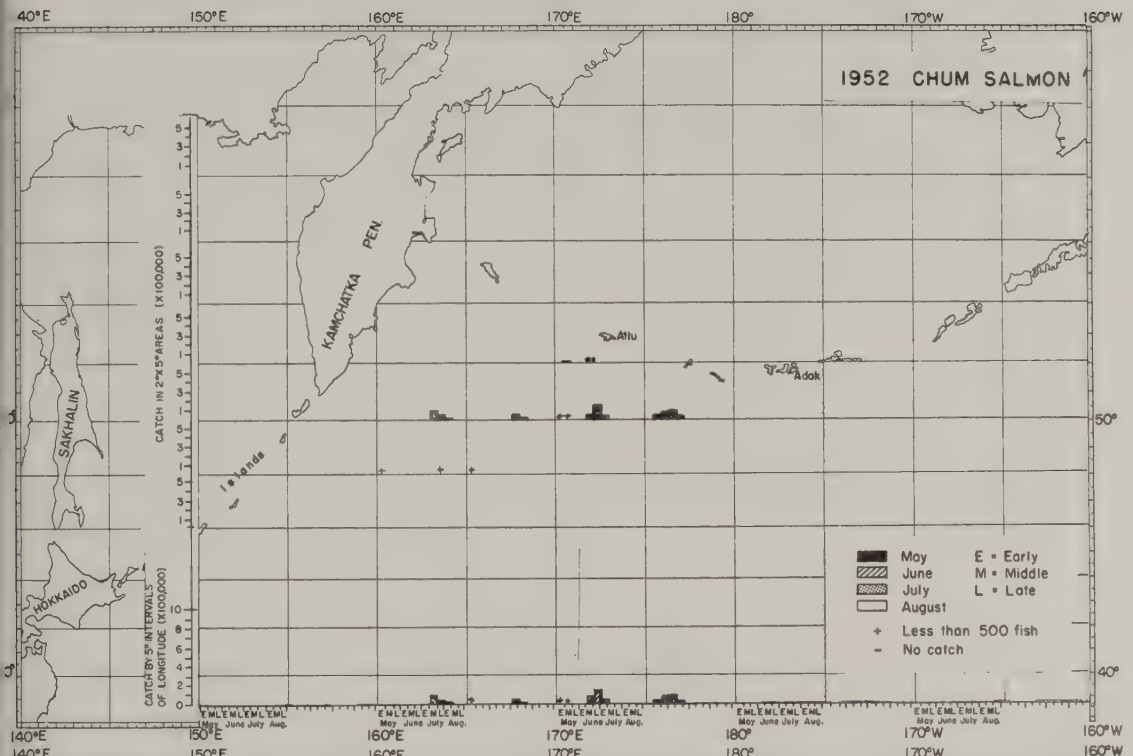
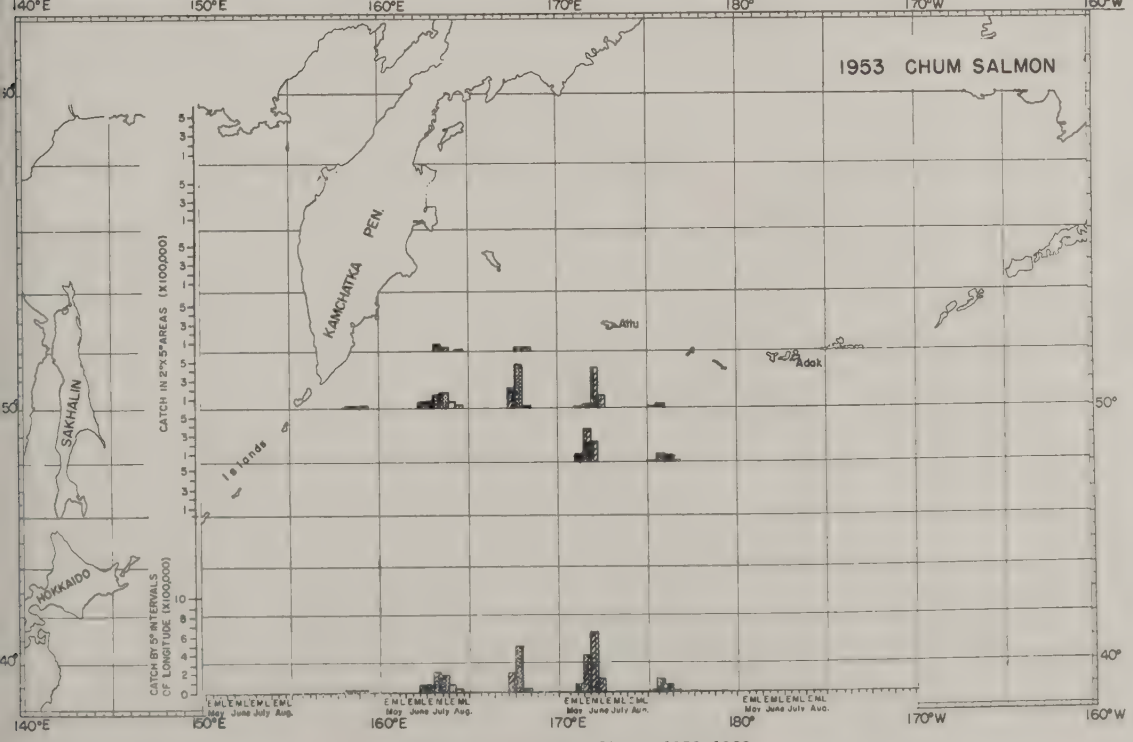
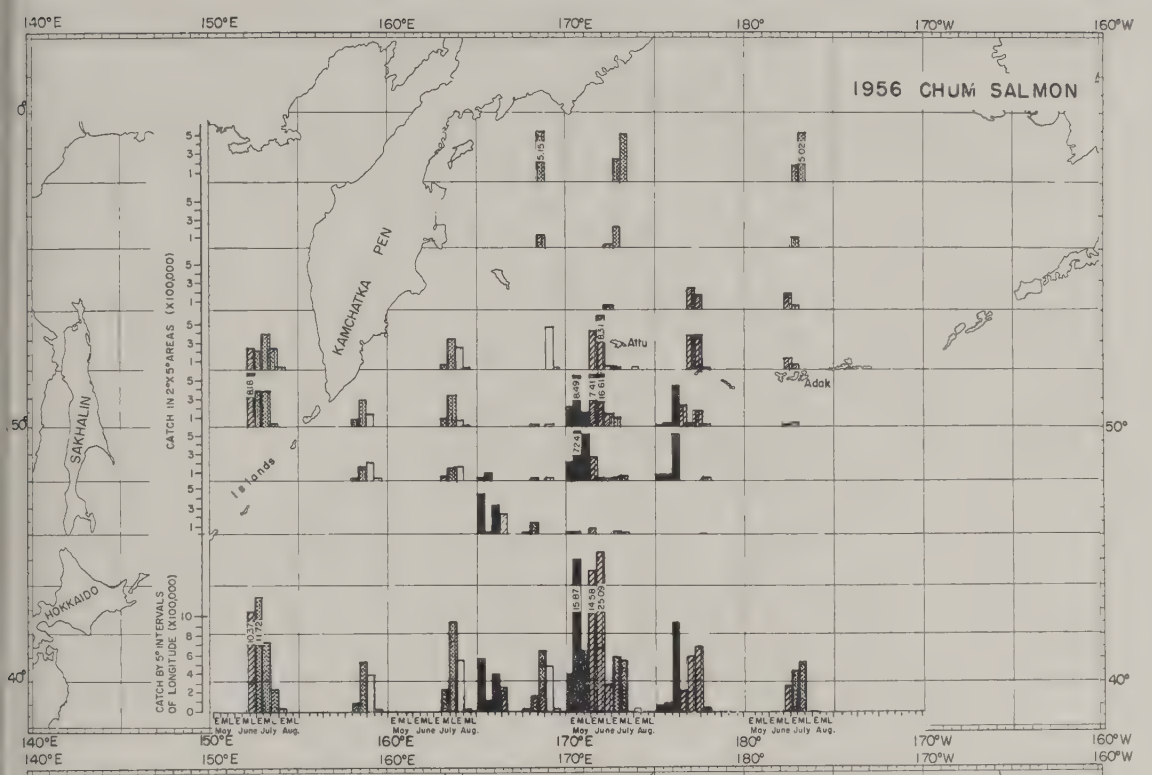
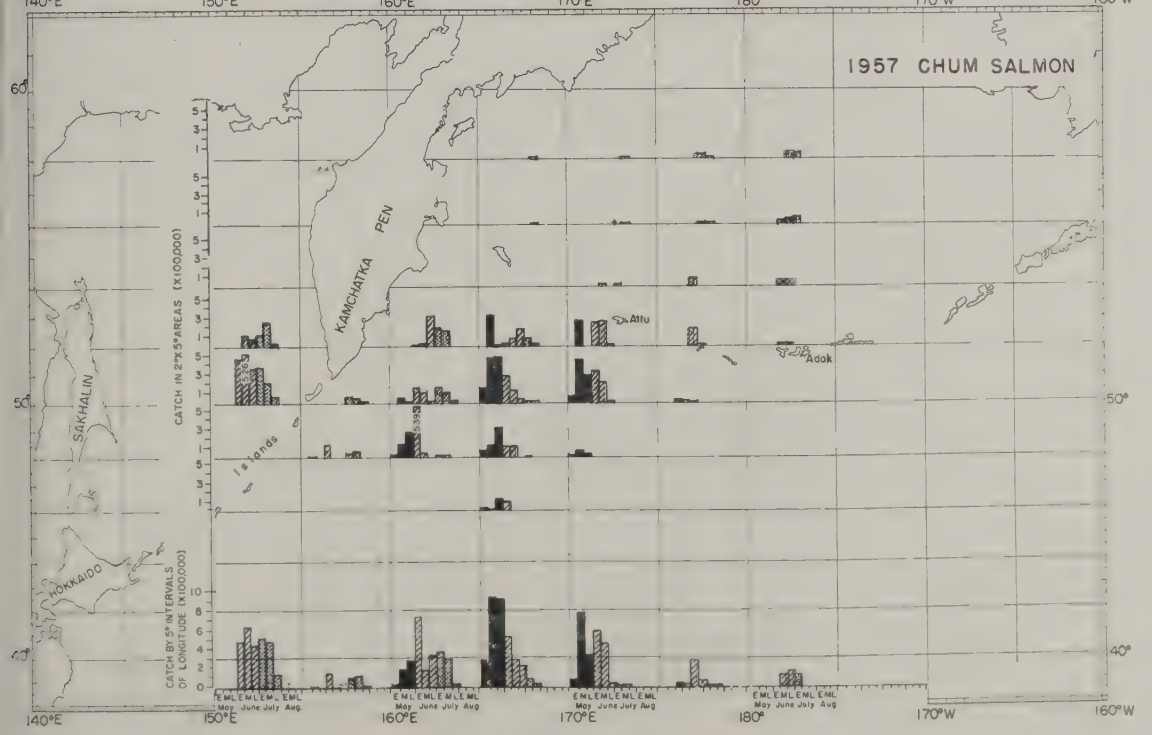




Appendix Figure C-2. Chum, 1952–1960.

Appendix Figure C-2. Continued.





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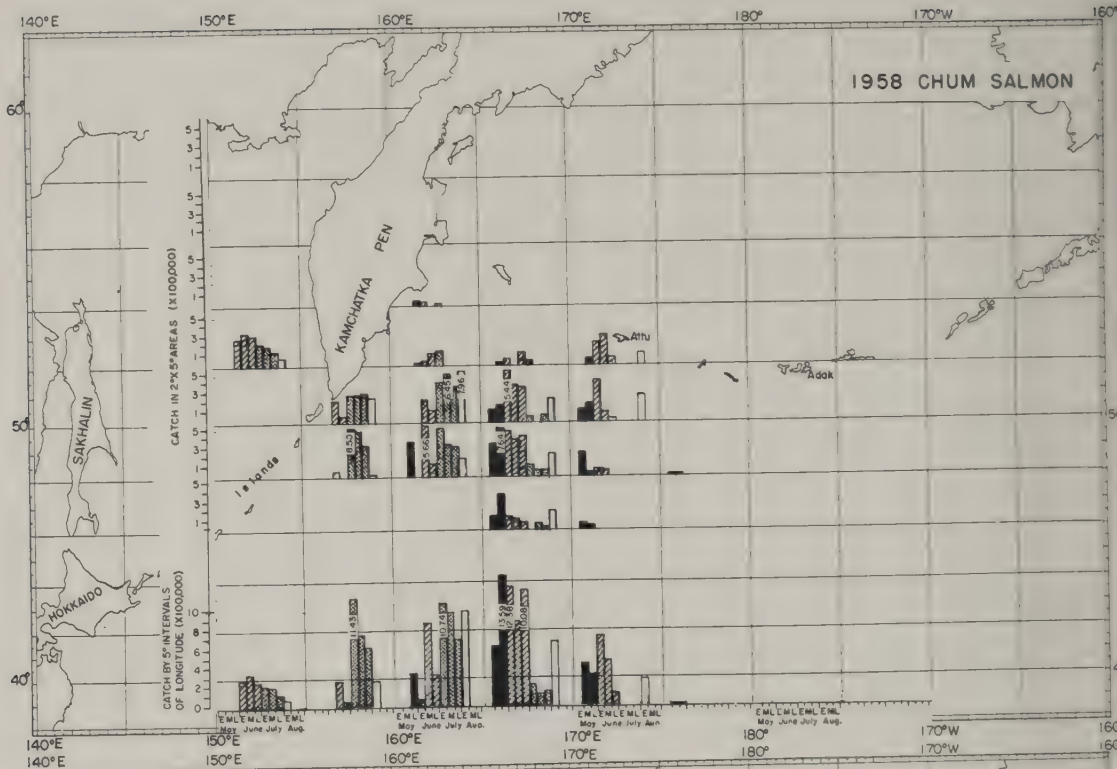
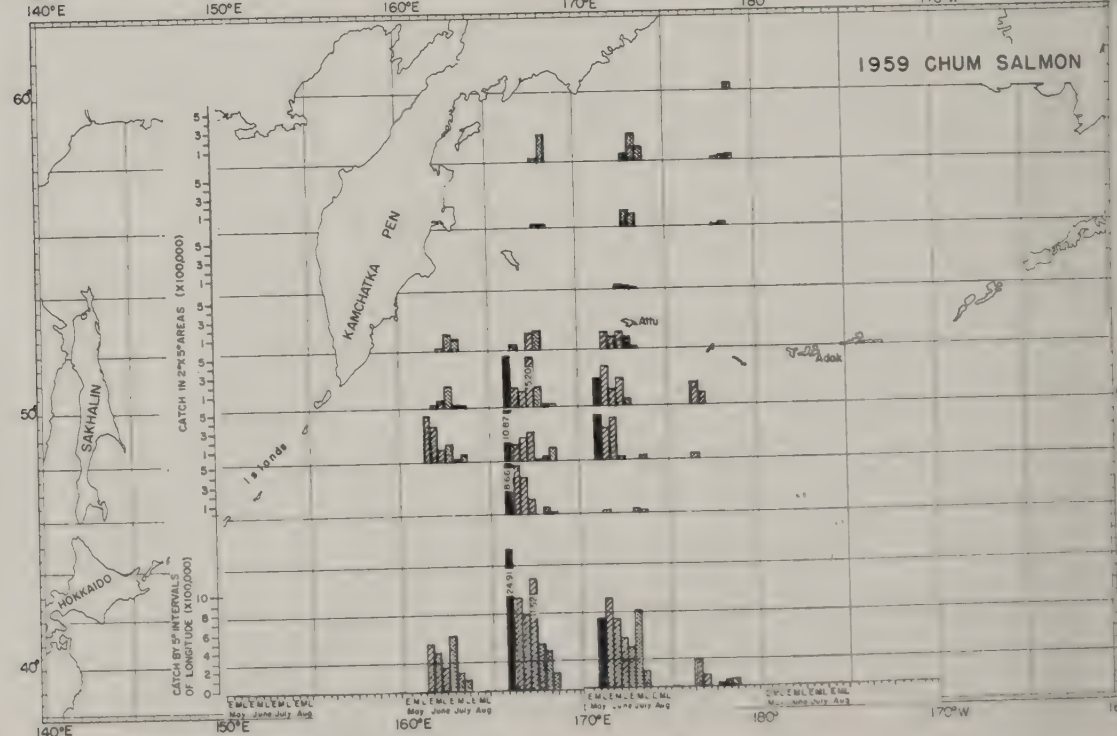
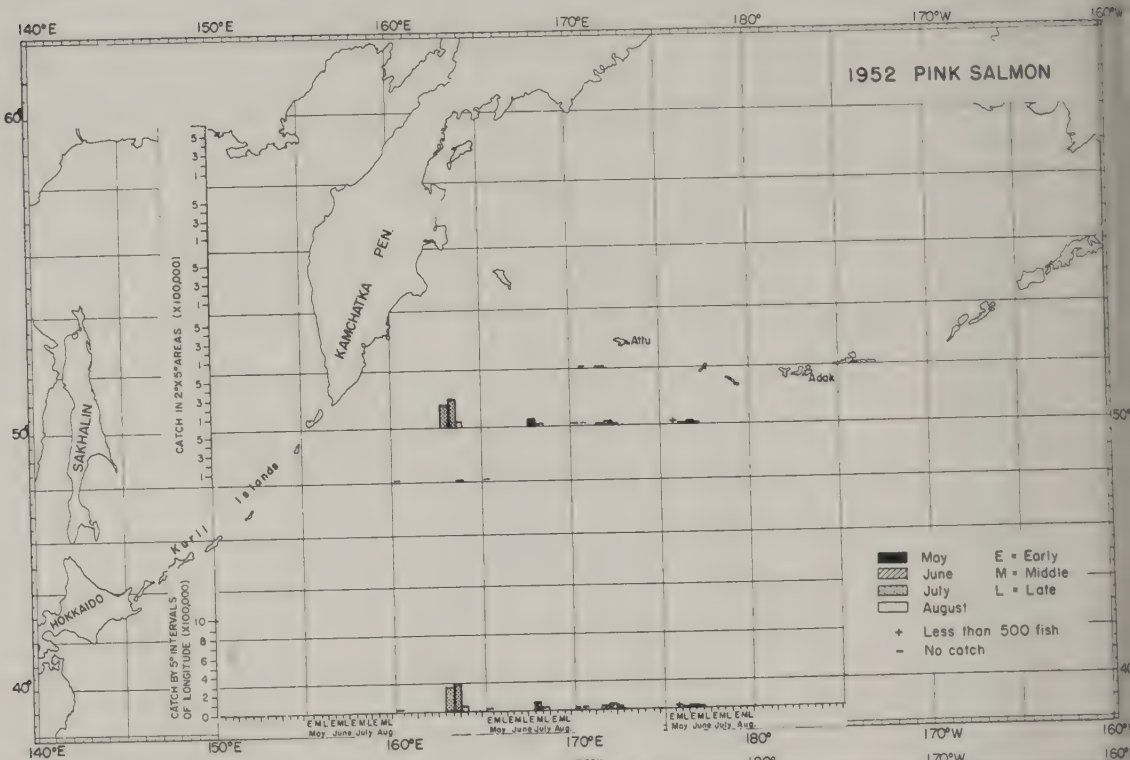
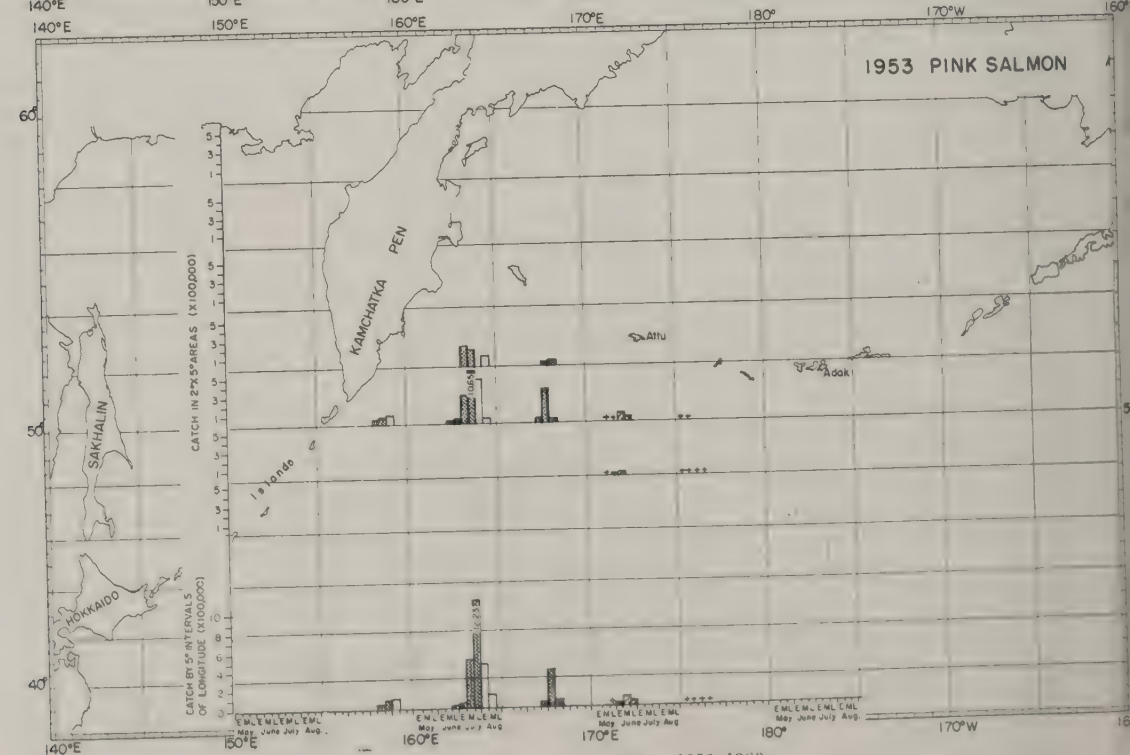




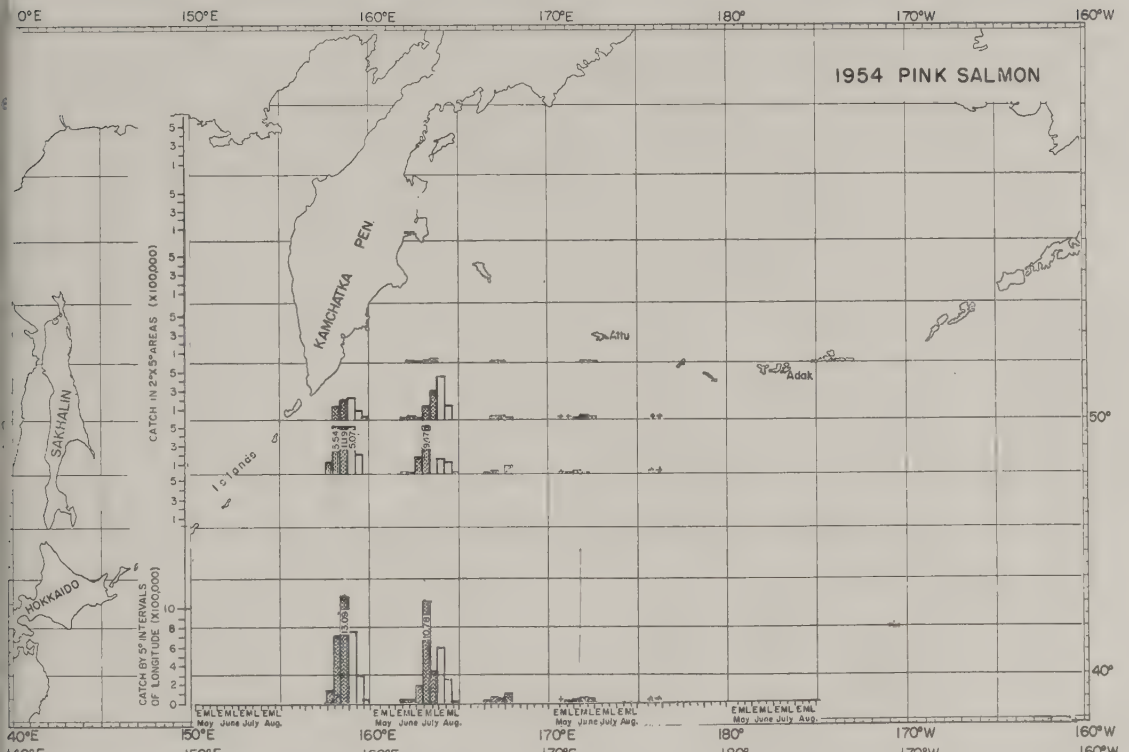
APPENDIX FIGURE C-2. Continued.

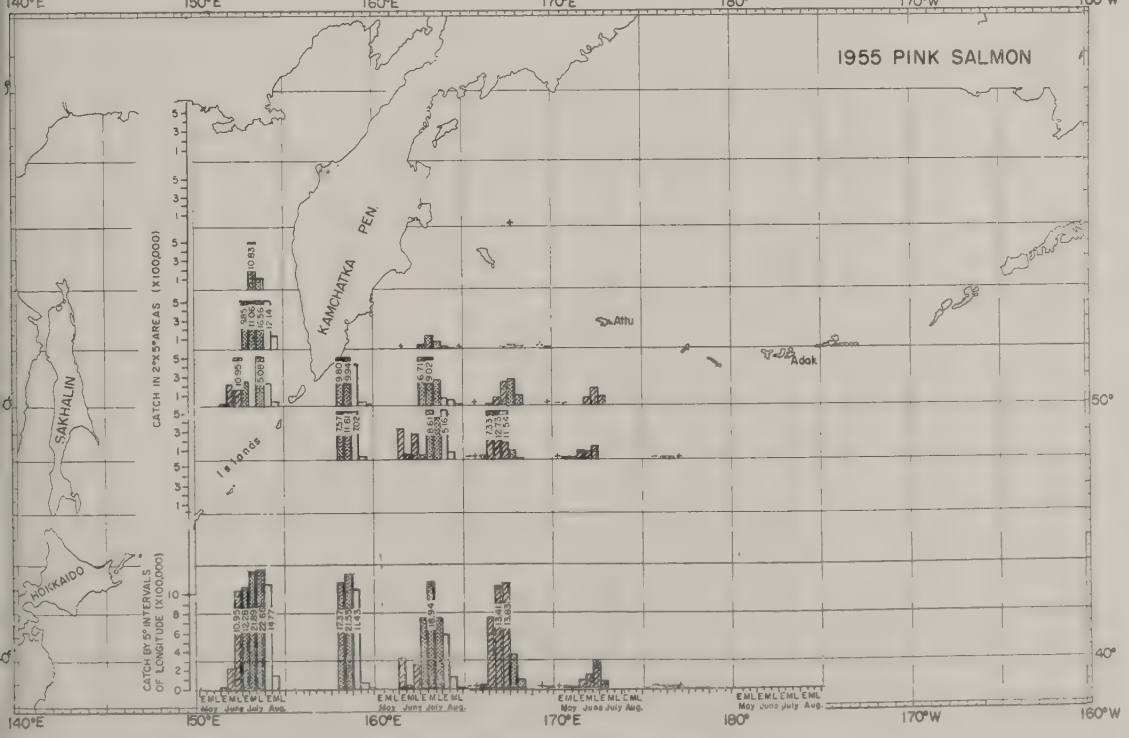
Appendix Figure C-2. Continued.





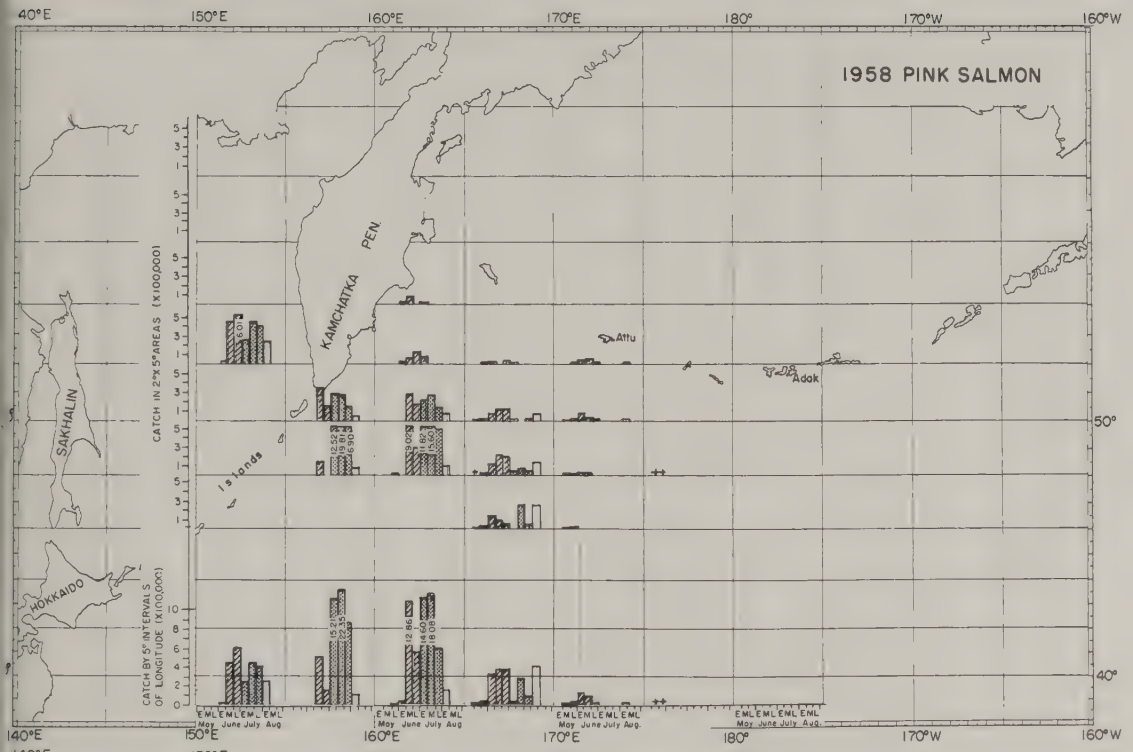
Appendix Figure C-3. Pink, 1952–1960.

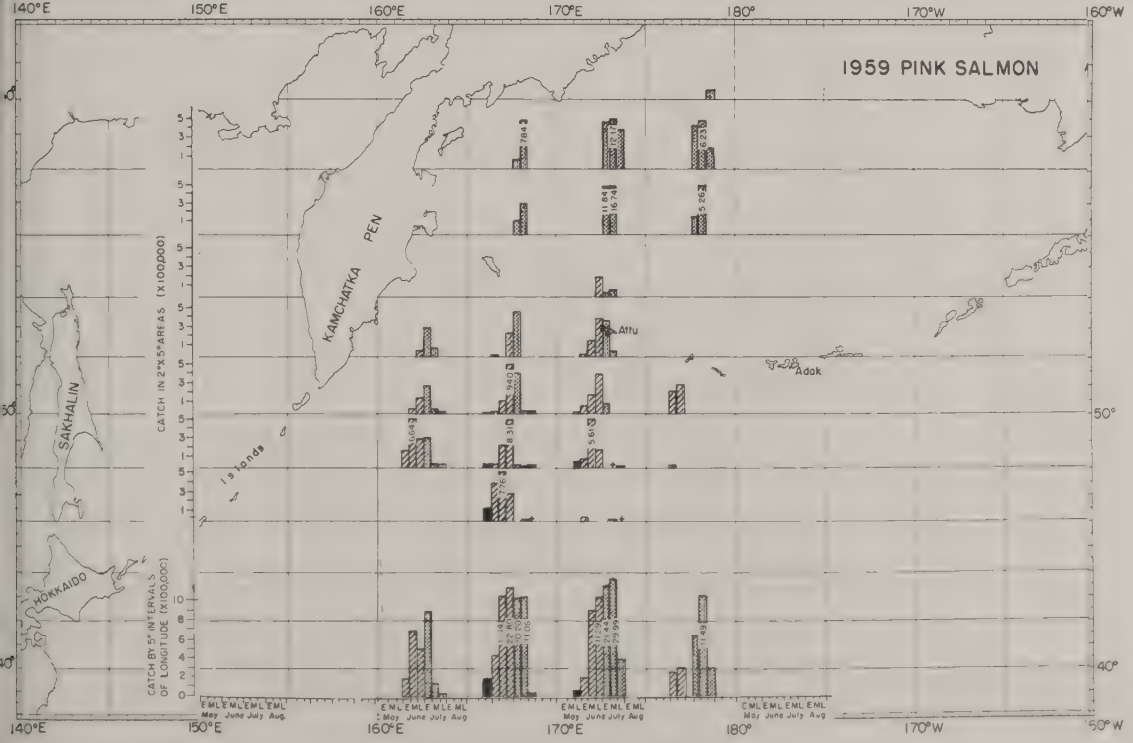




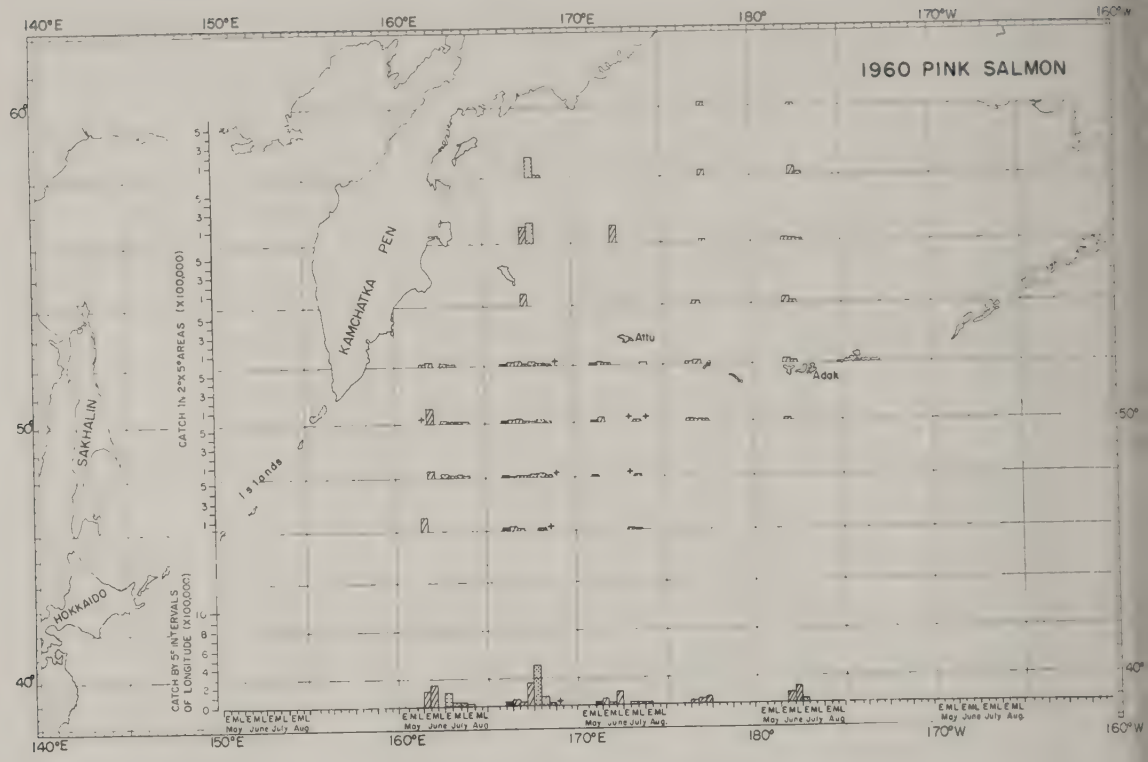
Appendix Figure C-3. Continued.

Appendix Figure C-3. Continued.





APPENDIX FIGURE C-3. Continued.



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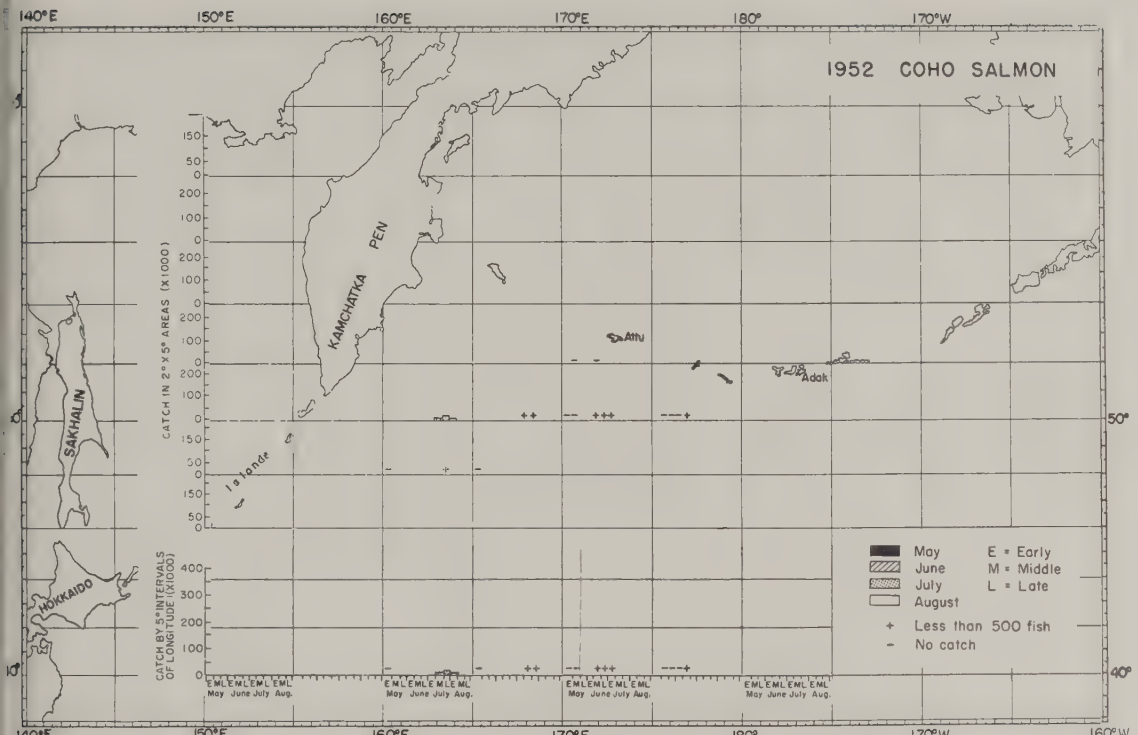
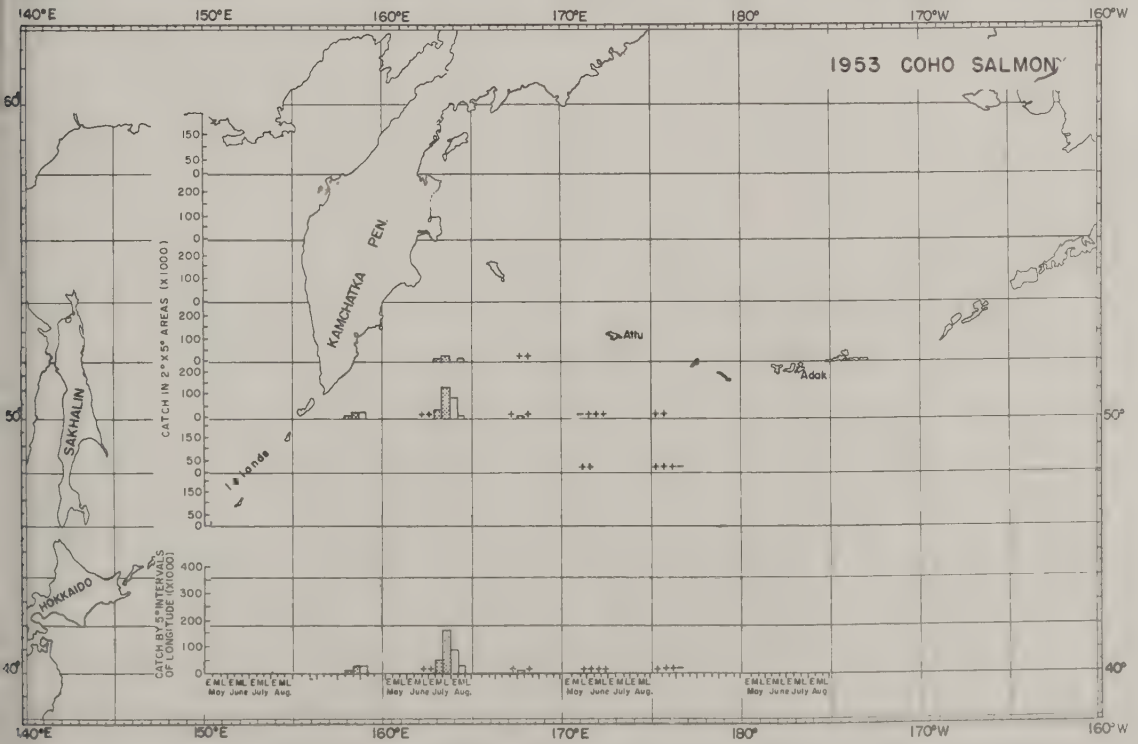
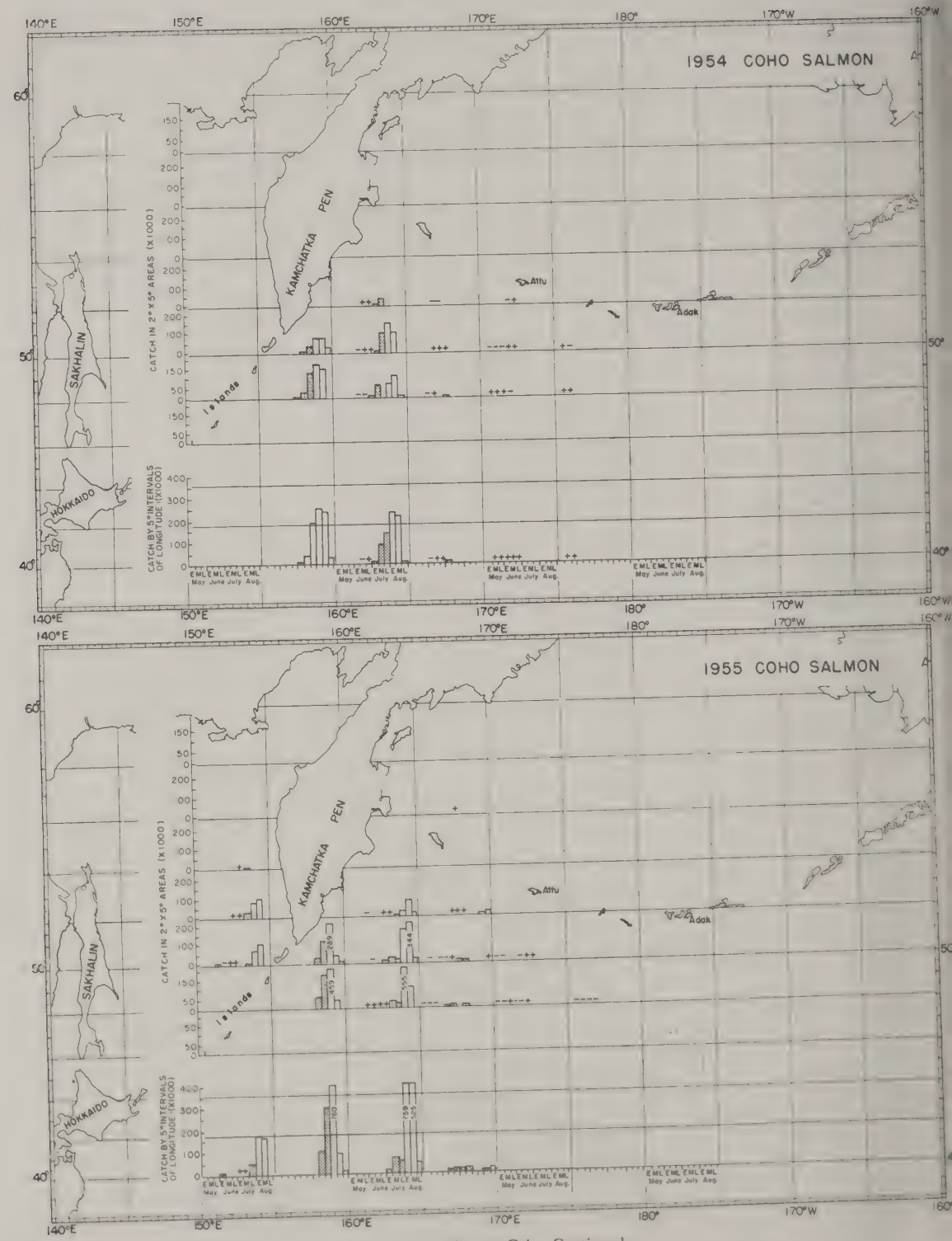




APPENDIX FIGURE C-4. Coho, 1952 1960.



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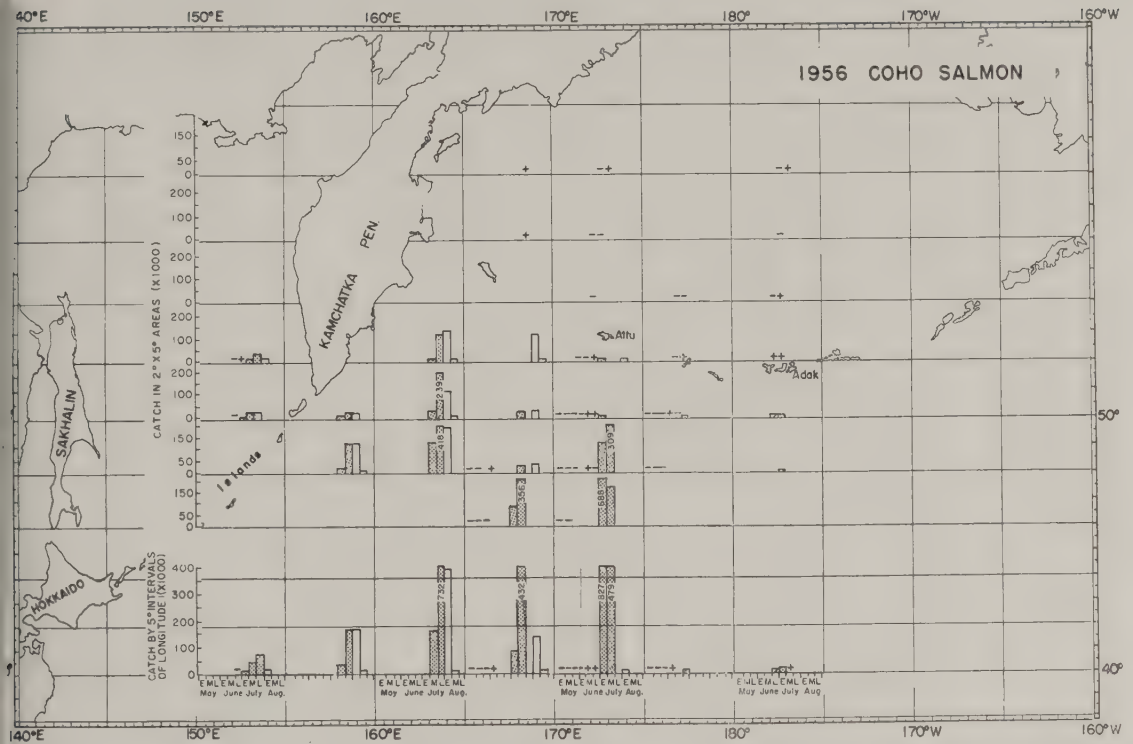

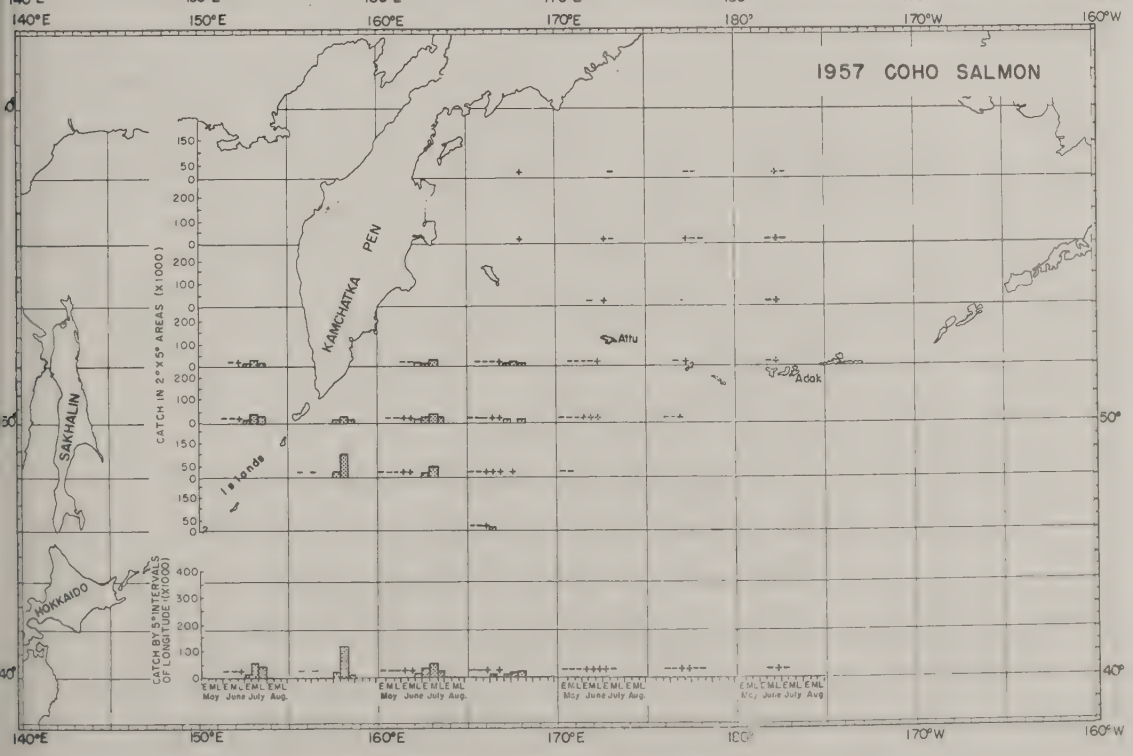

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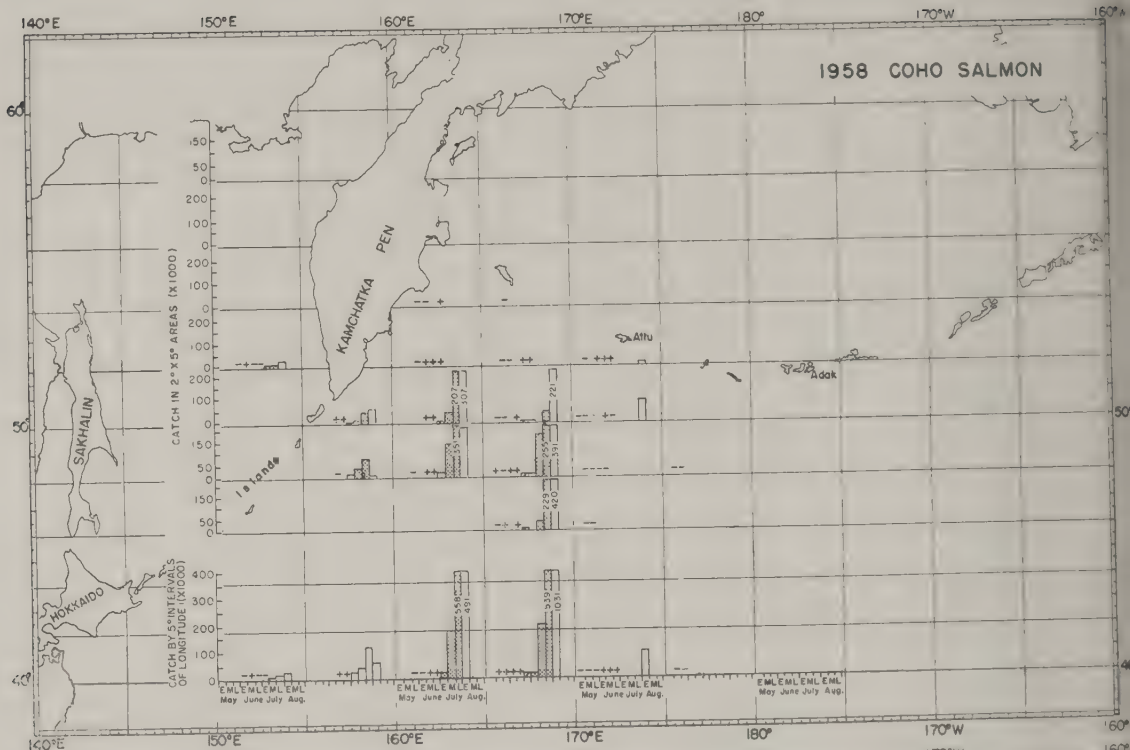

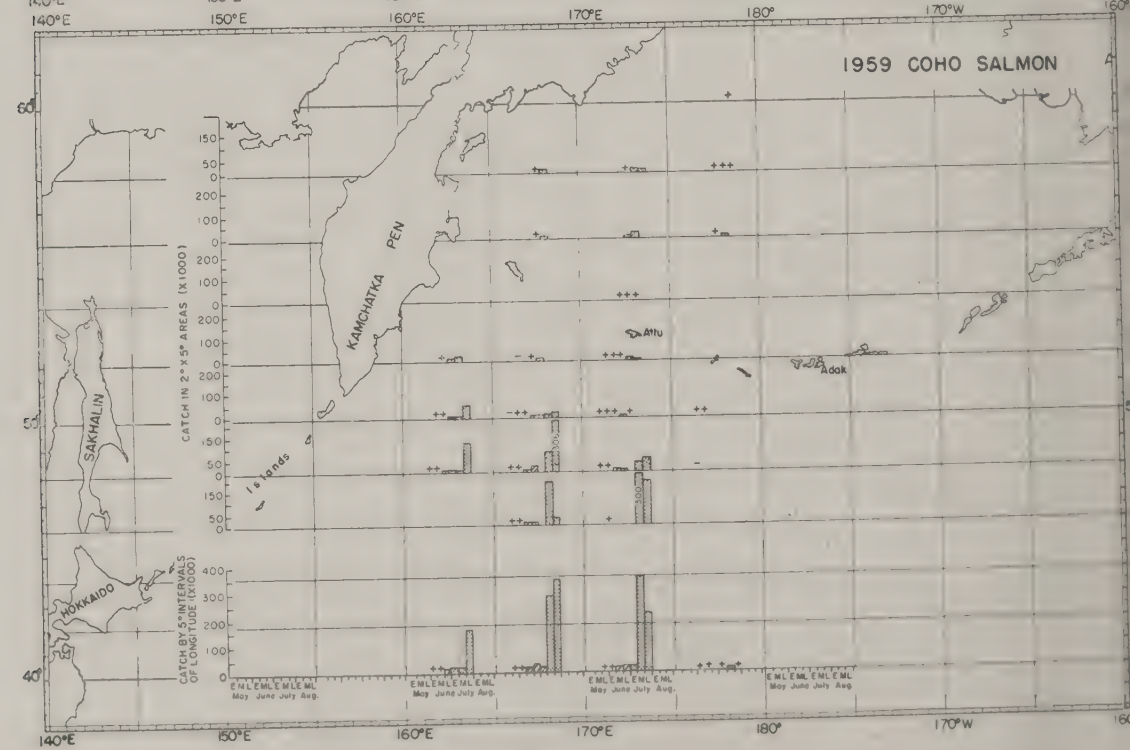

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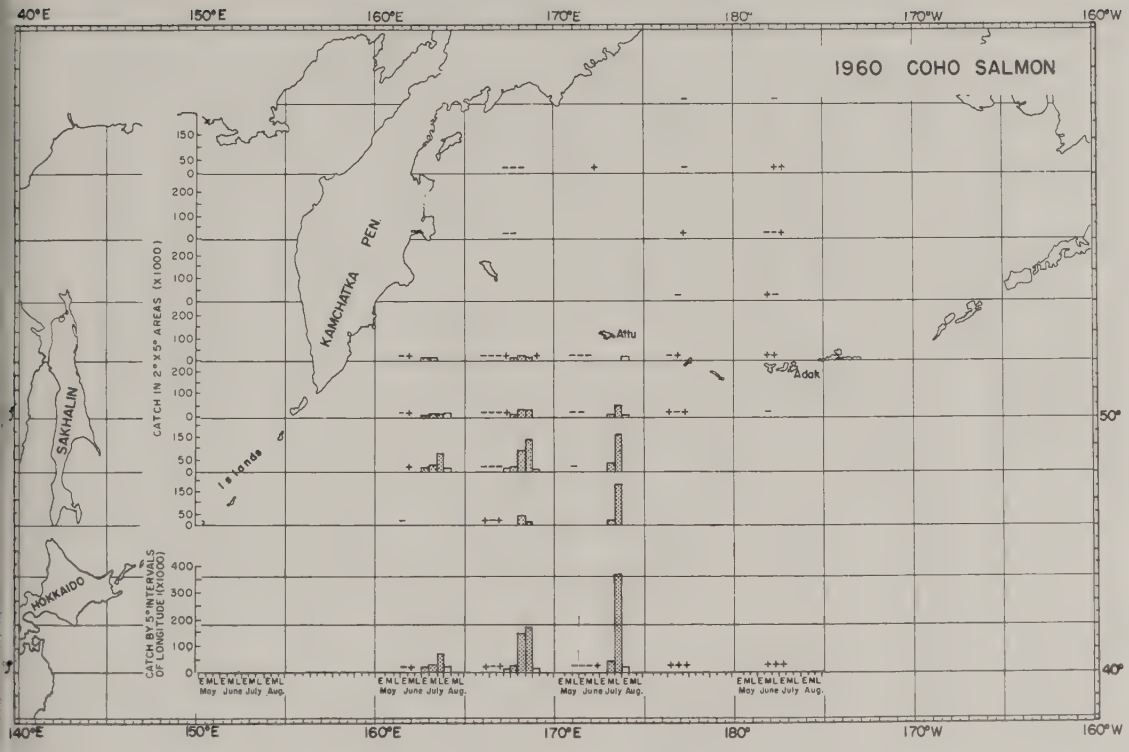
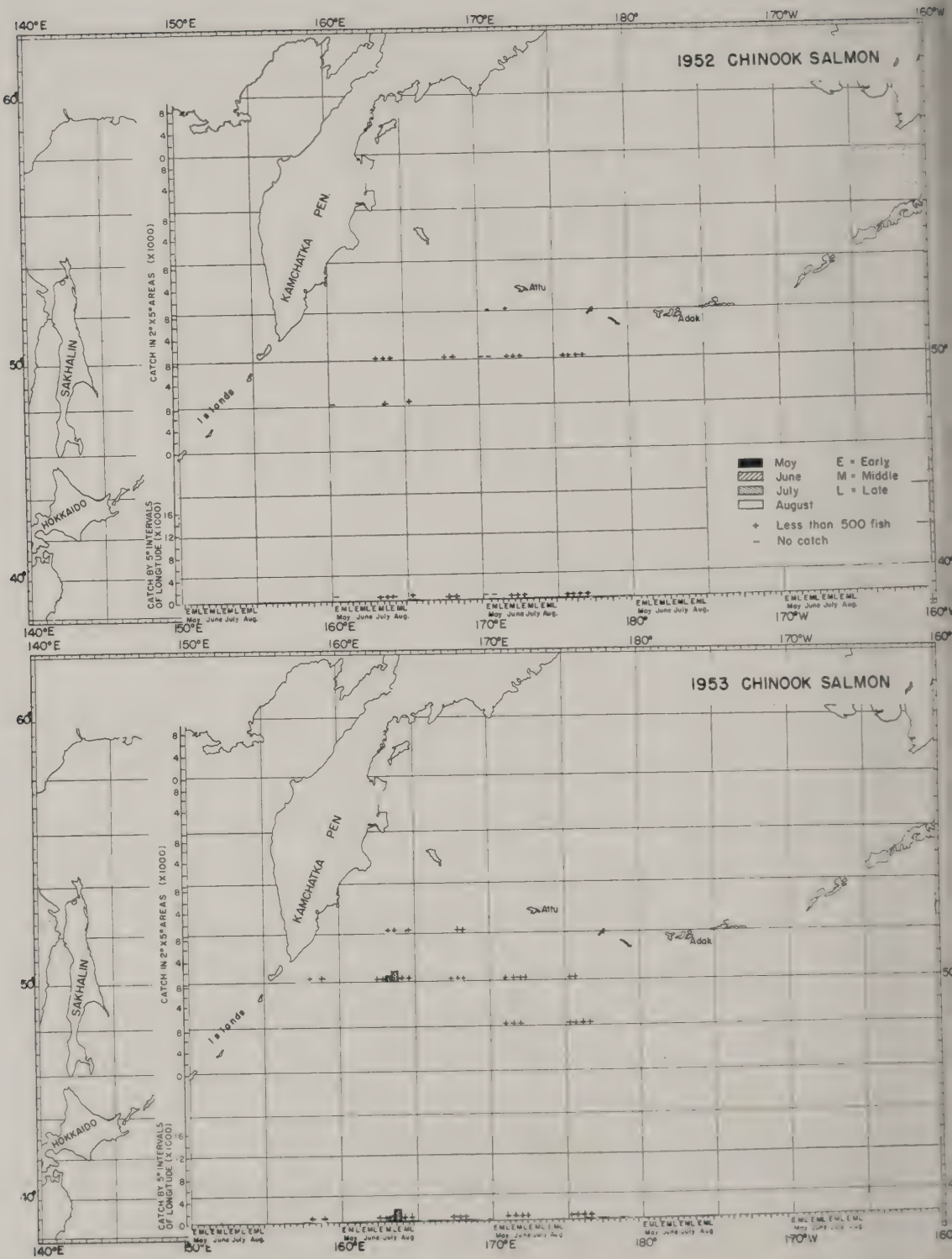
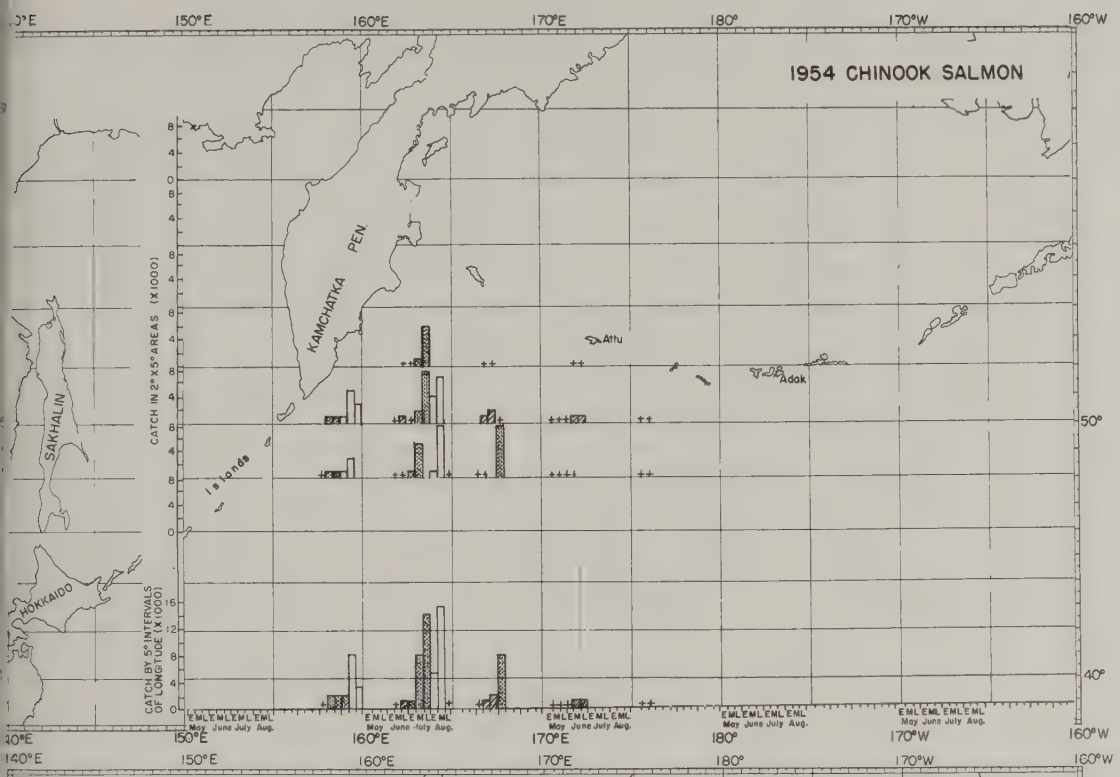


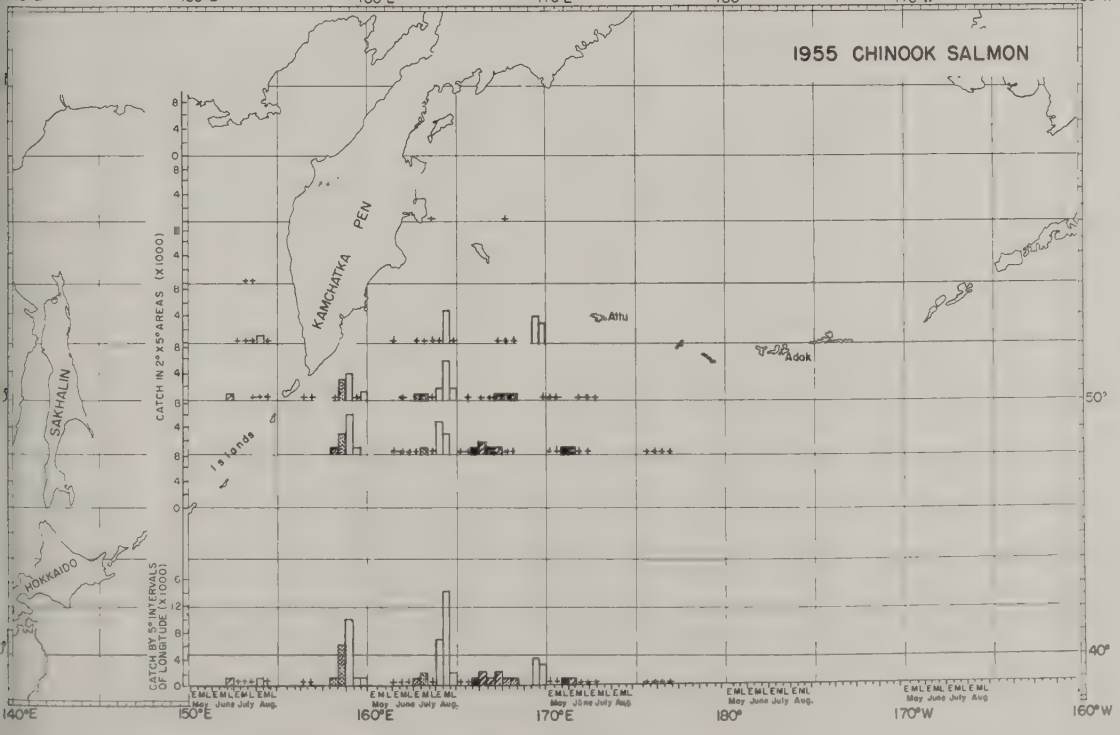
Appendix Figure C-4. Continued.

NOTE: The histogram for mid-July, area 7046, and that for the same time period by 5° intervals of longitude should each be increased by 100,000 fish.



Appendix Figure C-5. Chinook, 1952–1960.





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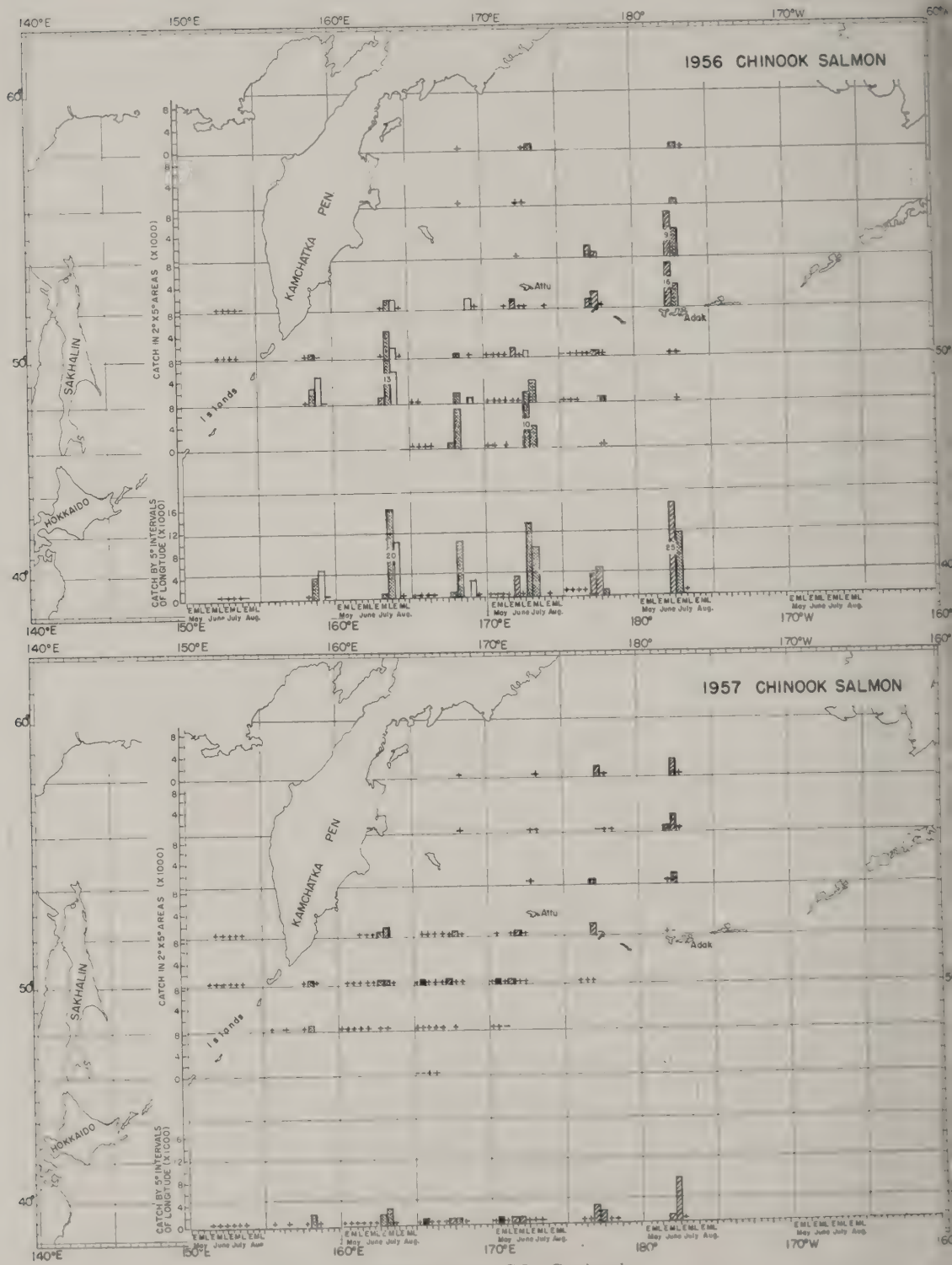

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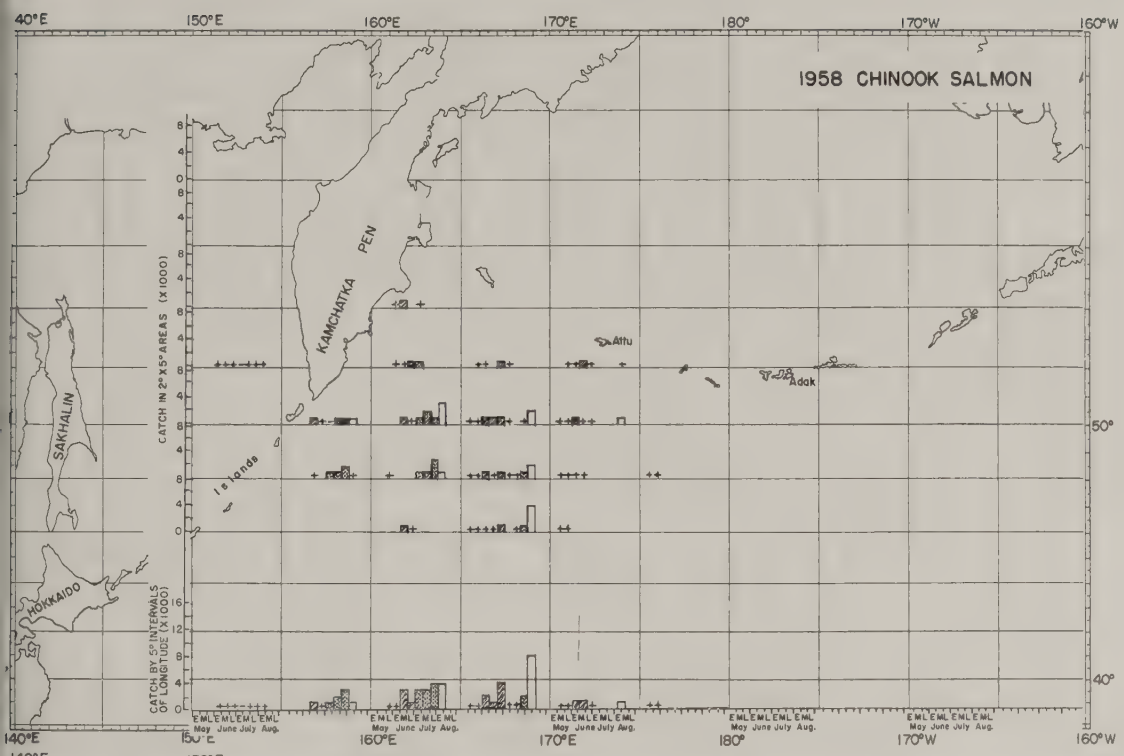

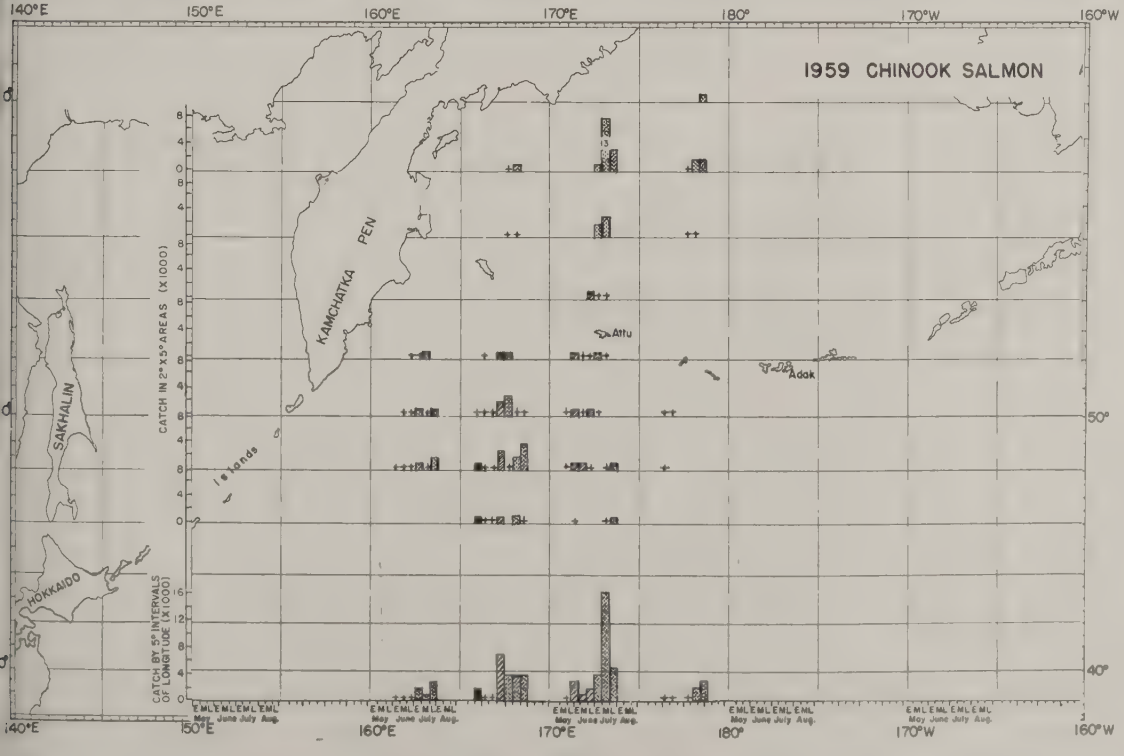

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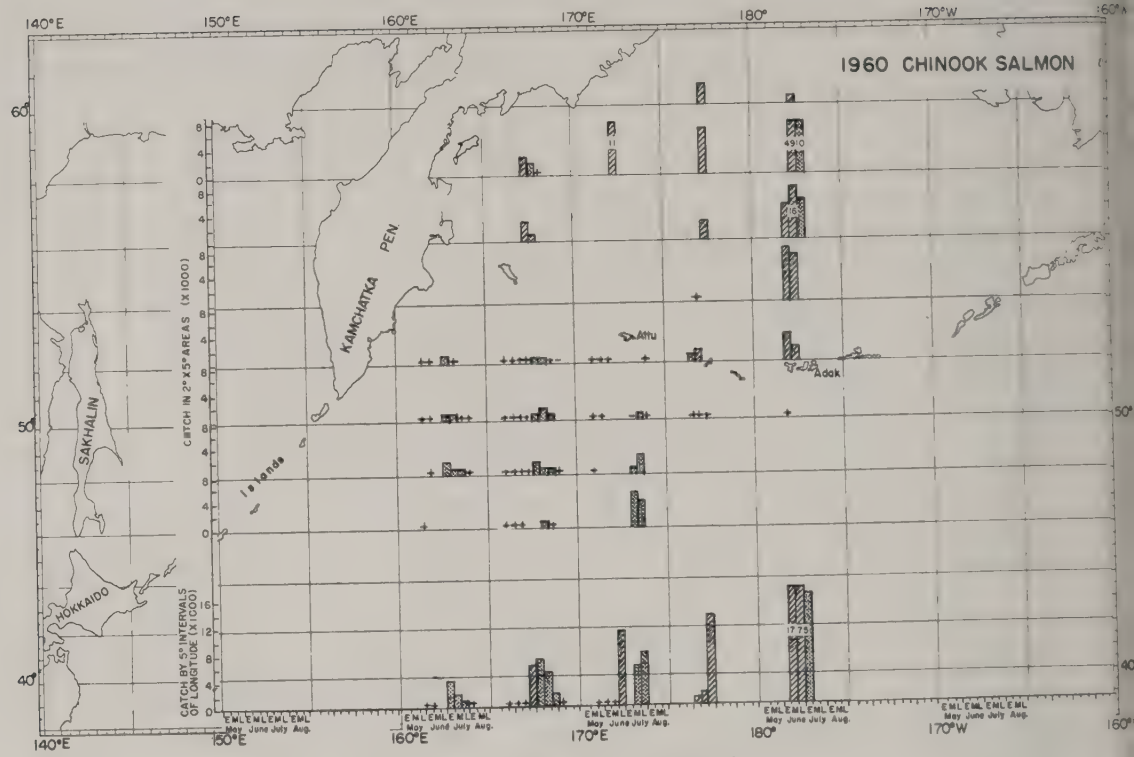


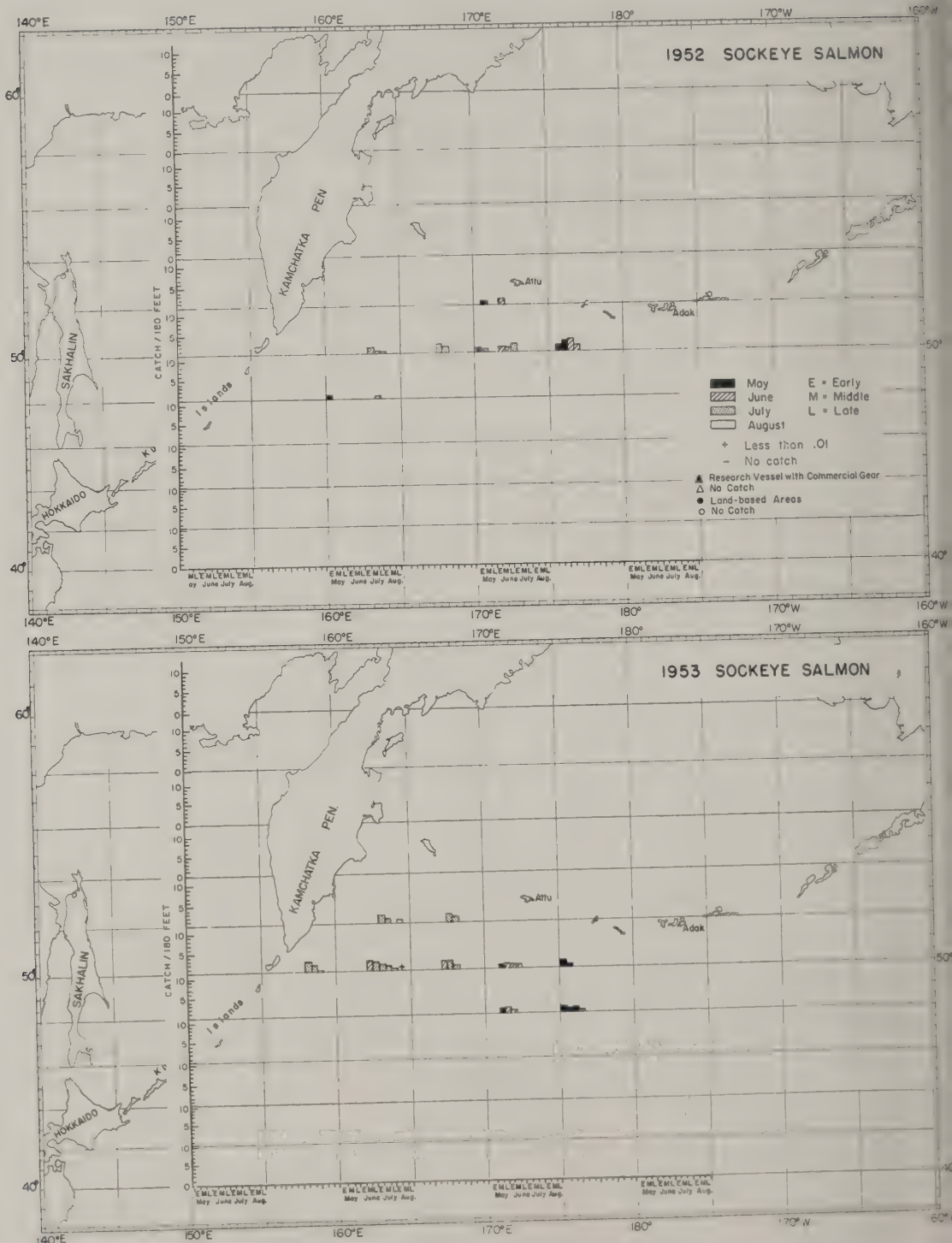
Appendix Figure C-5. Continued.

APPENDIX FIGURE D. CATCH PER UNIT OF EFFORT OF SOCKEYE, CHUM, PINK, COHO AND CHINOOK SALMON IN COMMERCIAL FISHERY REGIONS BY 10-DAY PERIOD AND STATISTICAL AREA, 1952–1960

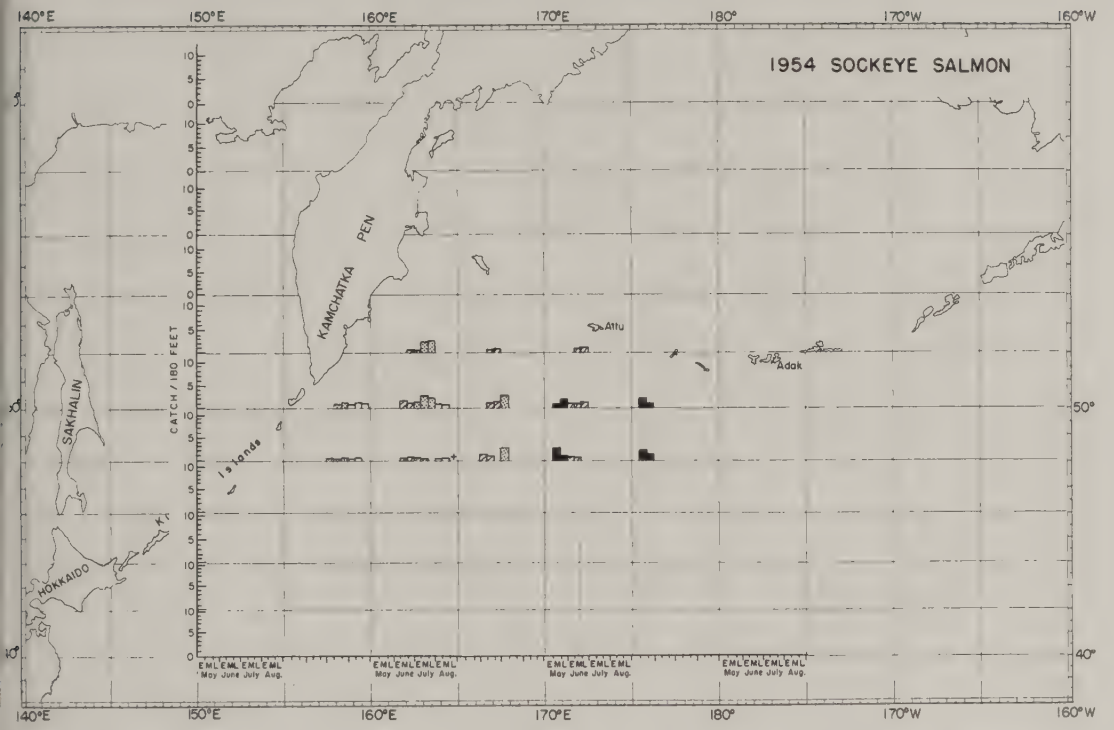
(Data for sockeye, chum, pink and coho salmon are shown in units of " catch per 180 feet " (one tan); those for chinook salmon are shown in units of " catch per 1,800 feet " (ten tans). Mothership data are illustrated by histograms; data from research and training vessels operating in the land-based region, by dots; data from research vessels using commercial gear, by triangles.)

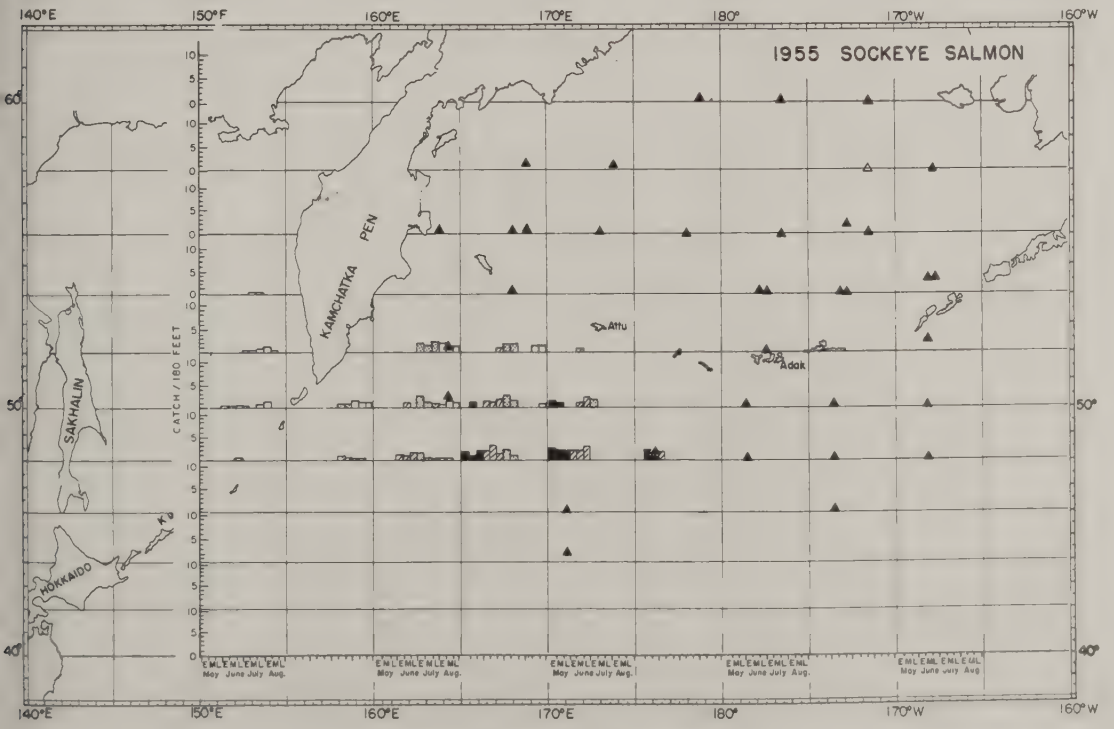
Page

D-1. Sockeye 428
D-2. Chum 433
D-3. Pink 438
D-4. Coho 443
D-5. Chinook 448



Appendix Figure D-1. Sockeye, 1952–1960.





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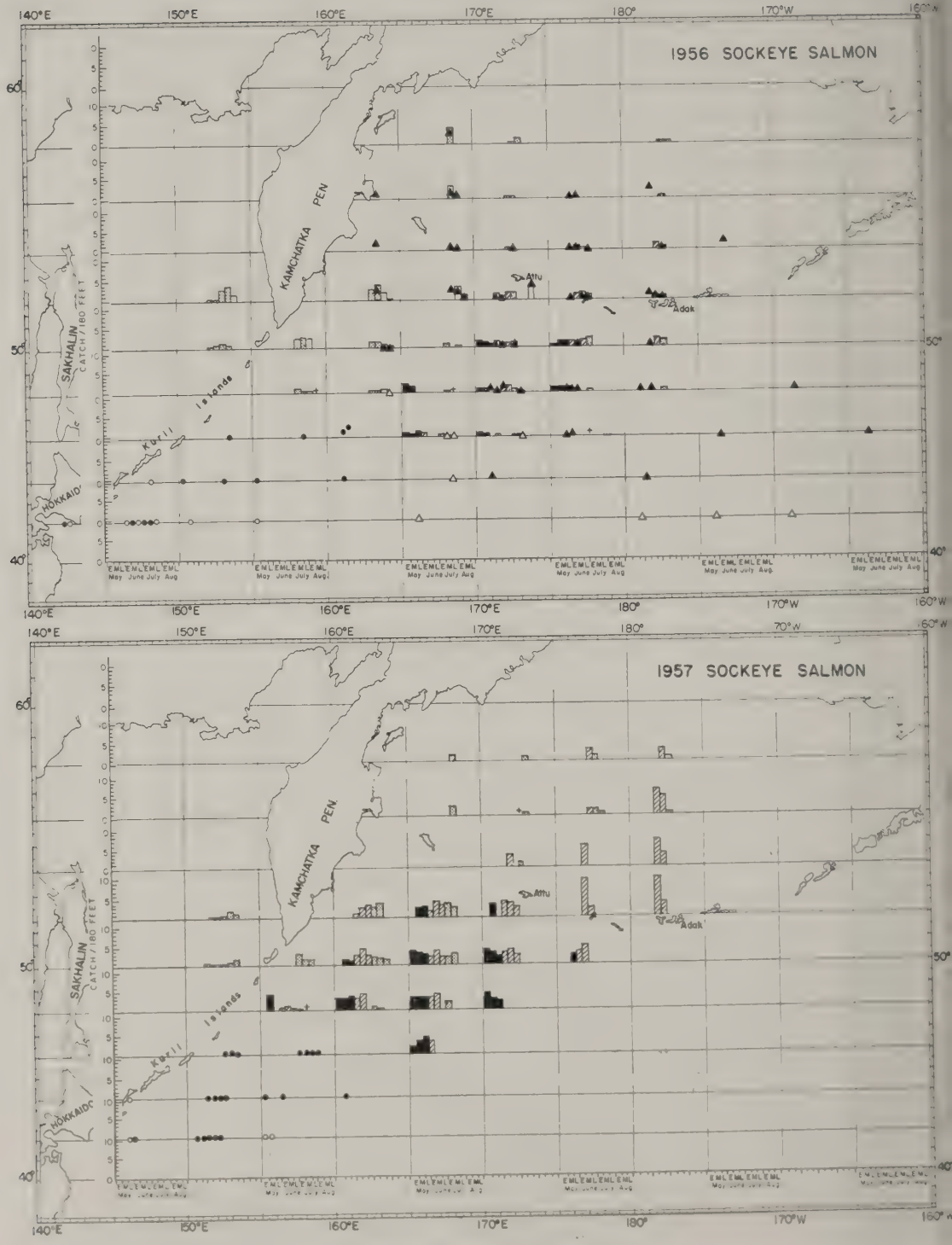

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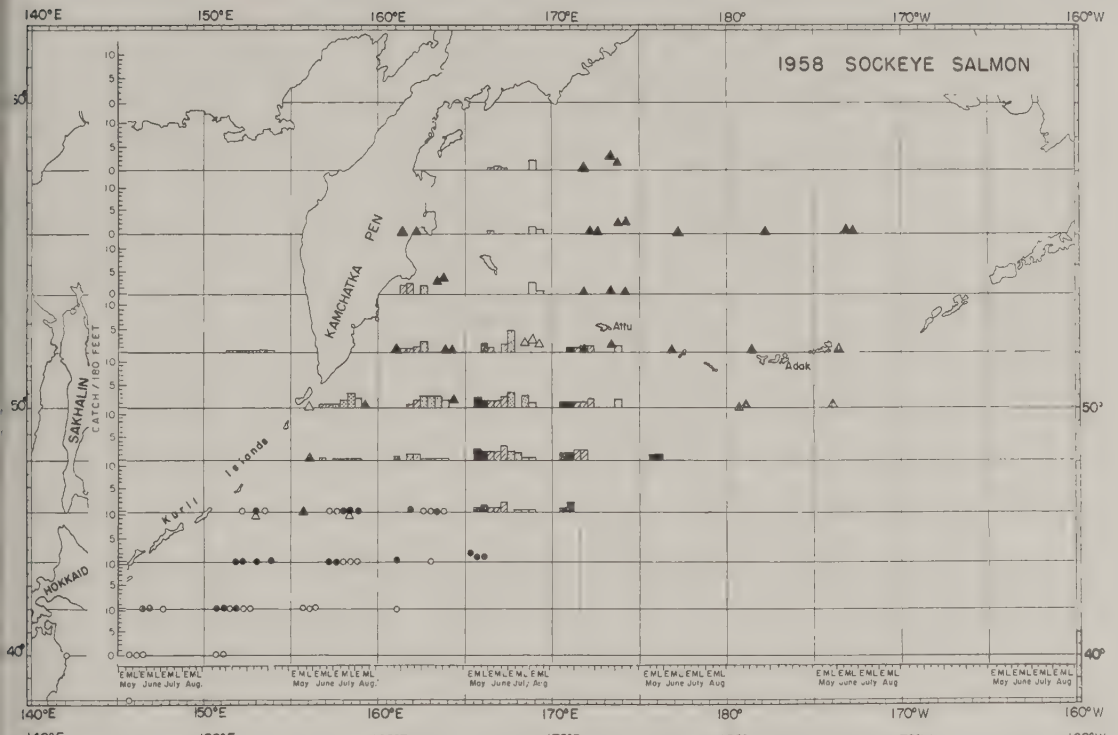

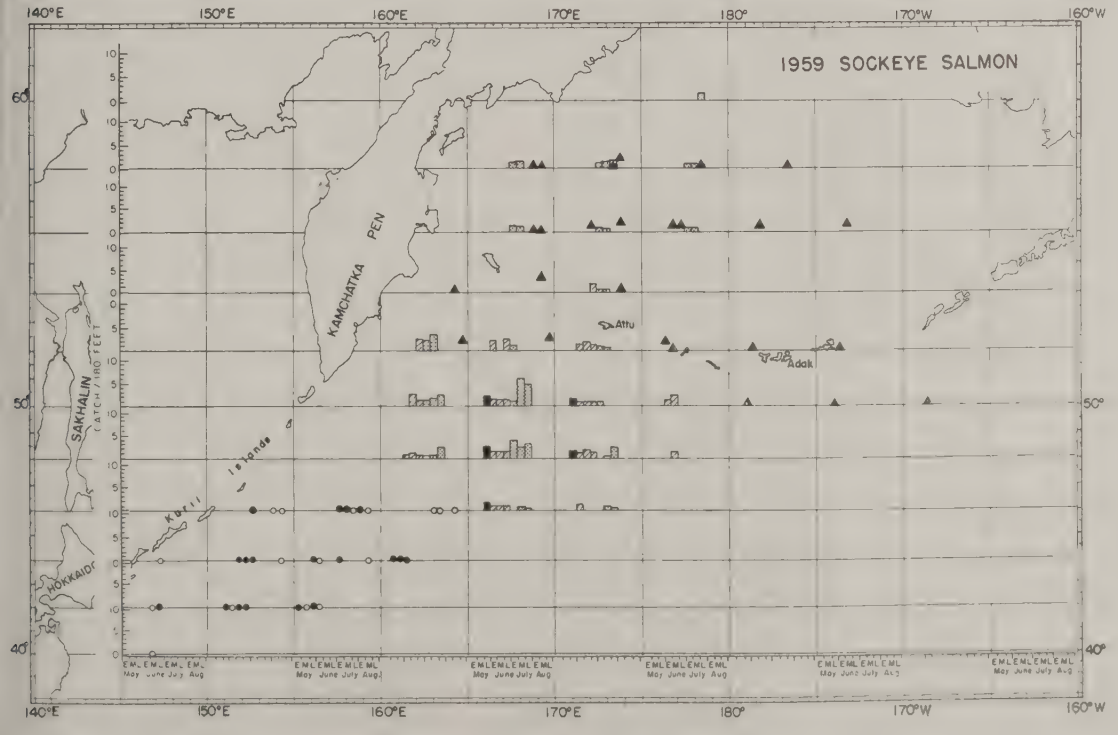

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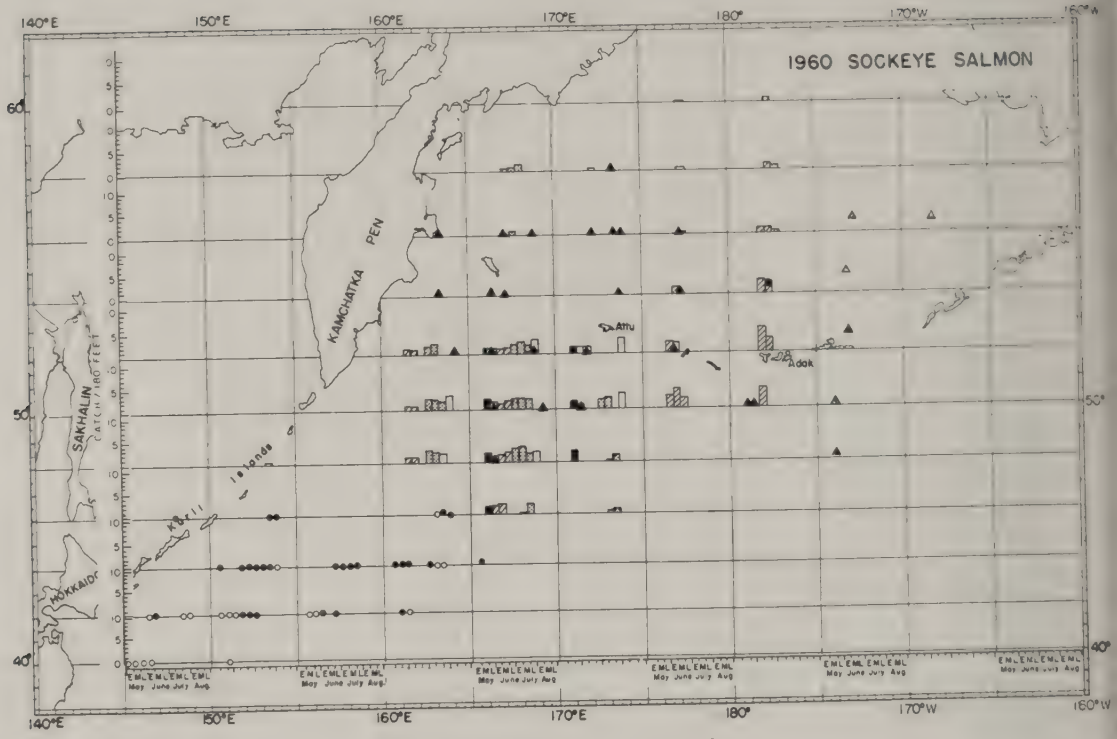

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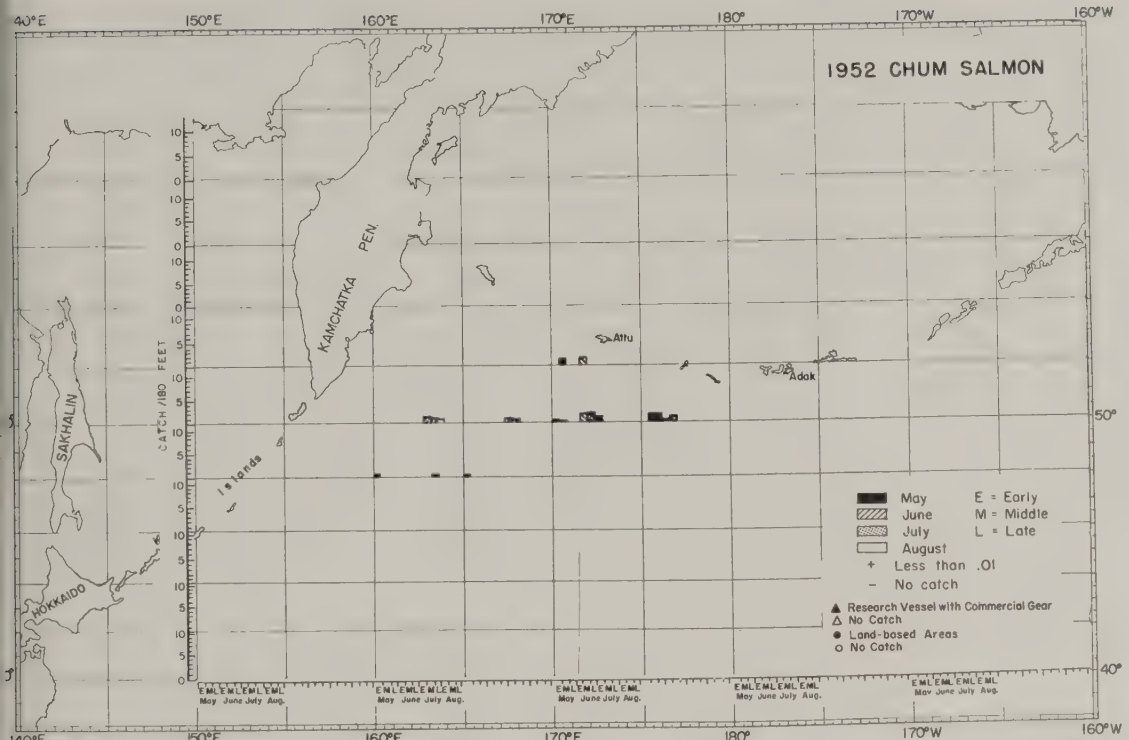
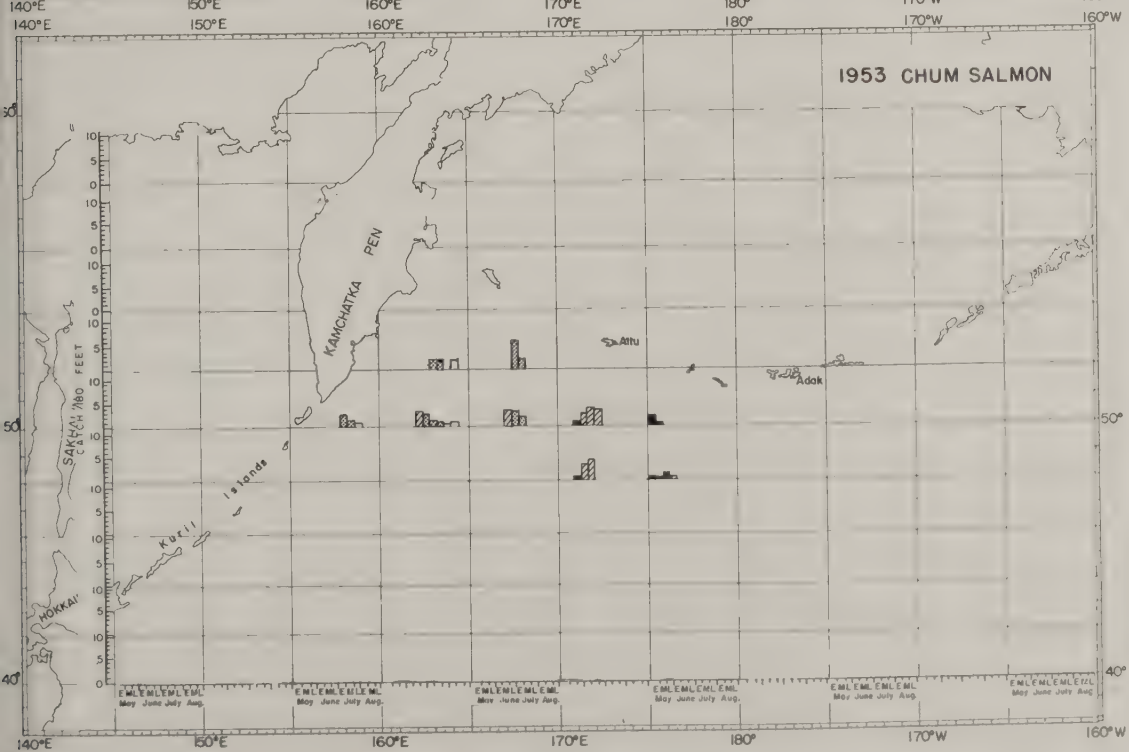
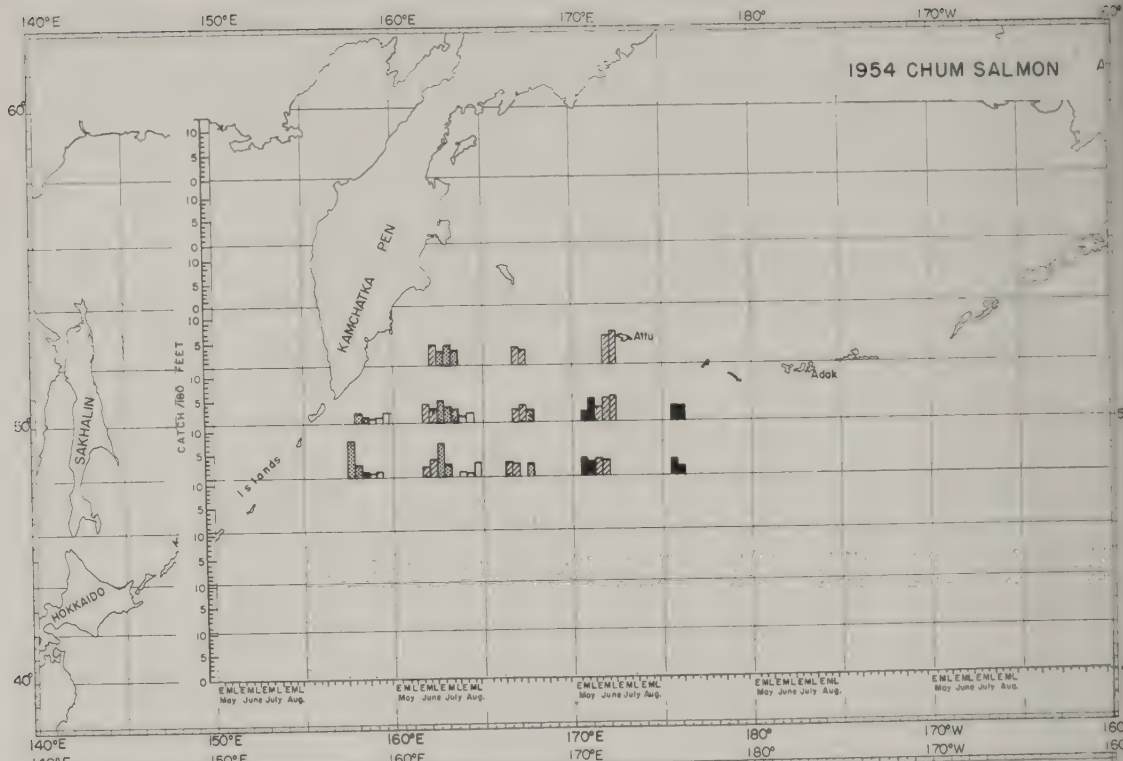




APPENDIX FIGURE D-2. Chum, 1952–1960.



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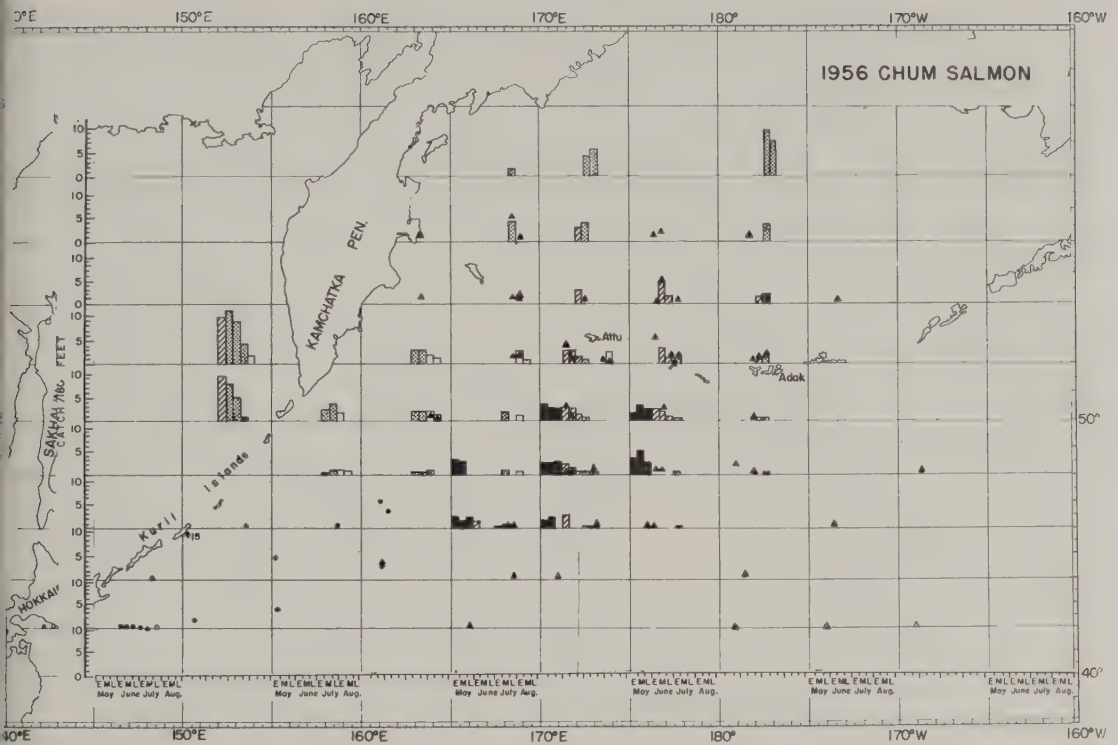

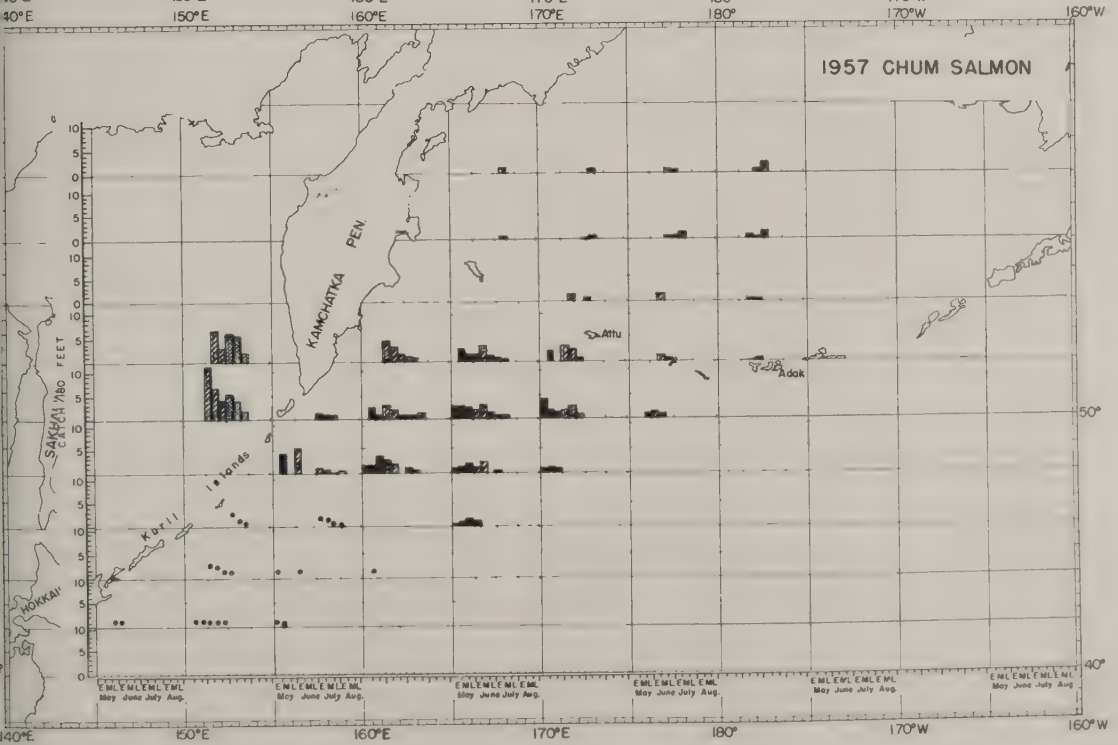

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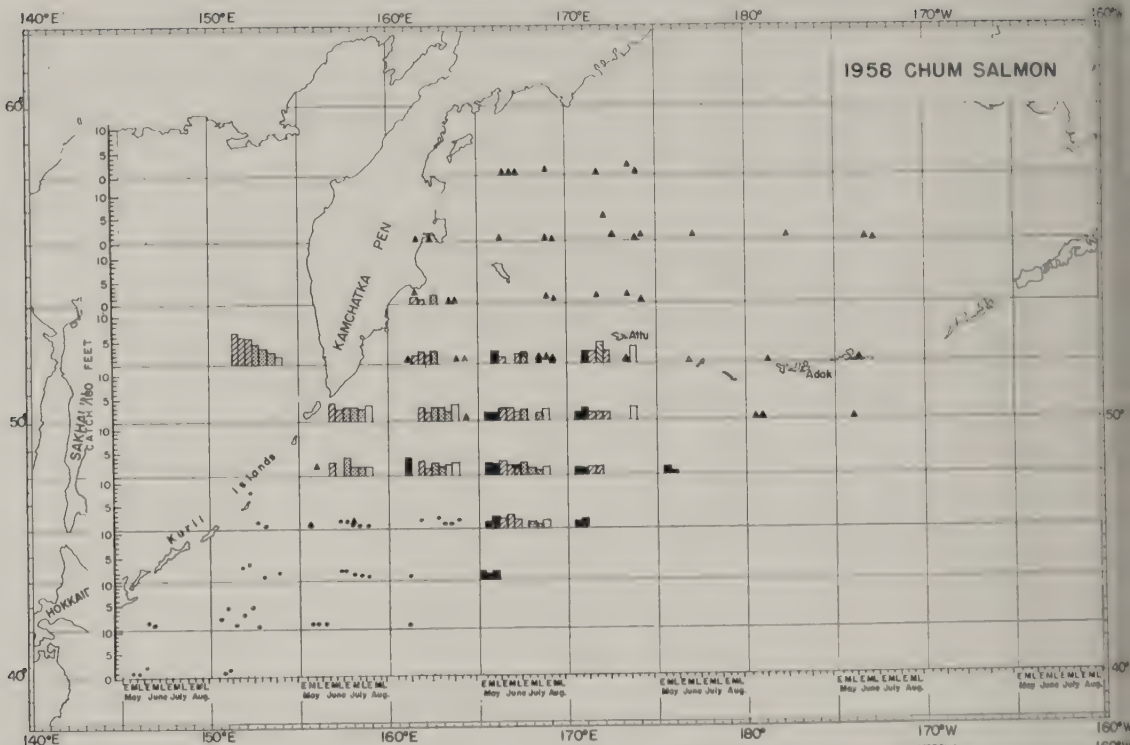

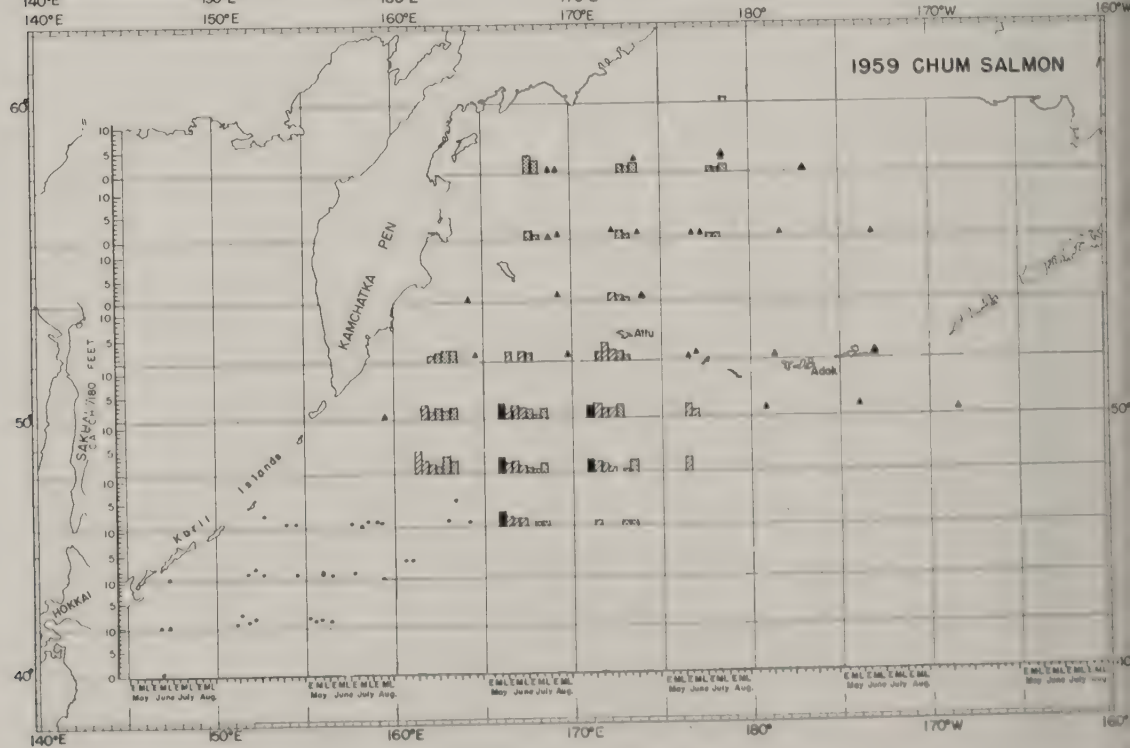

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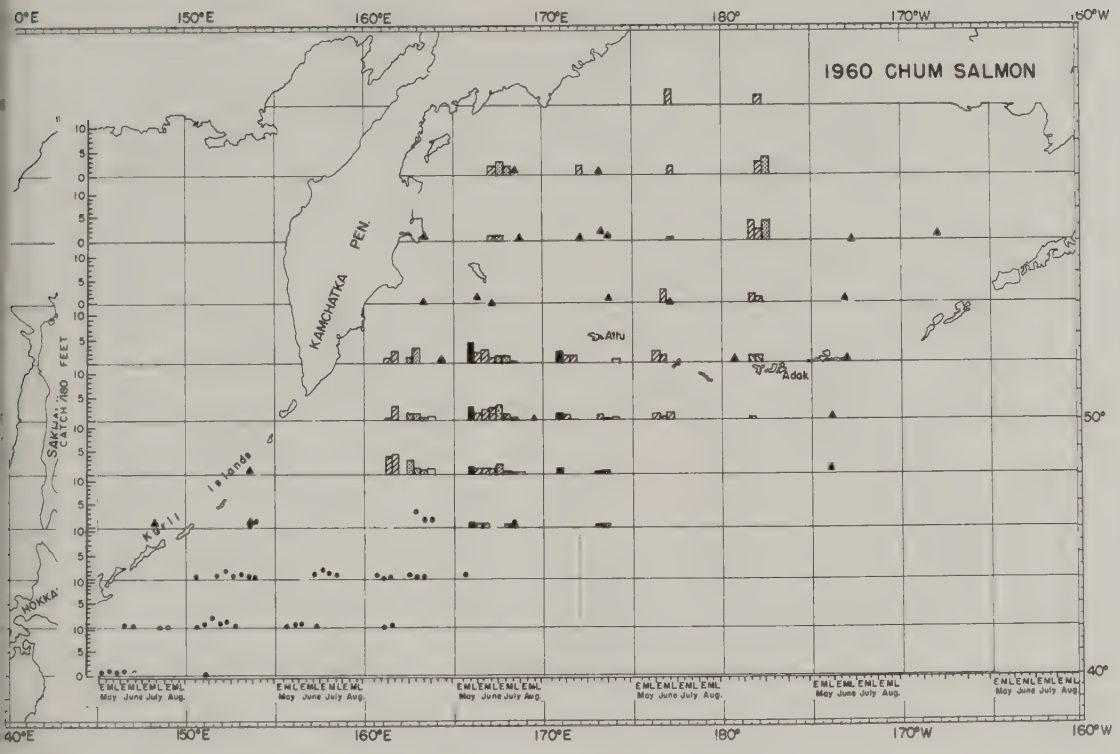

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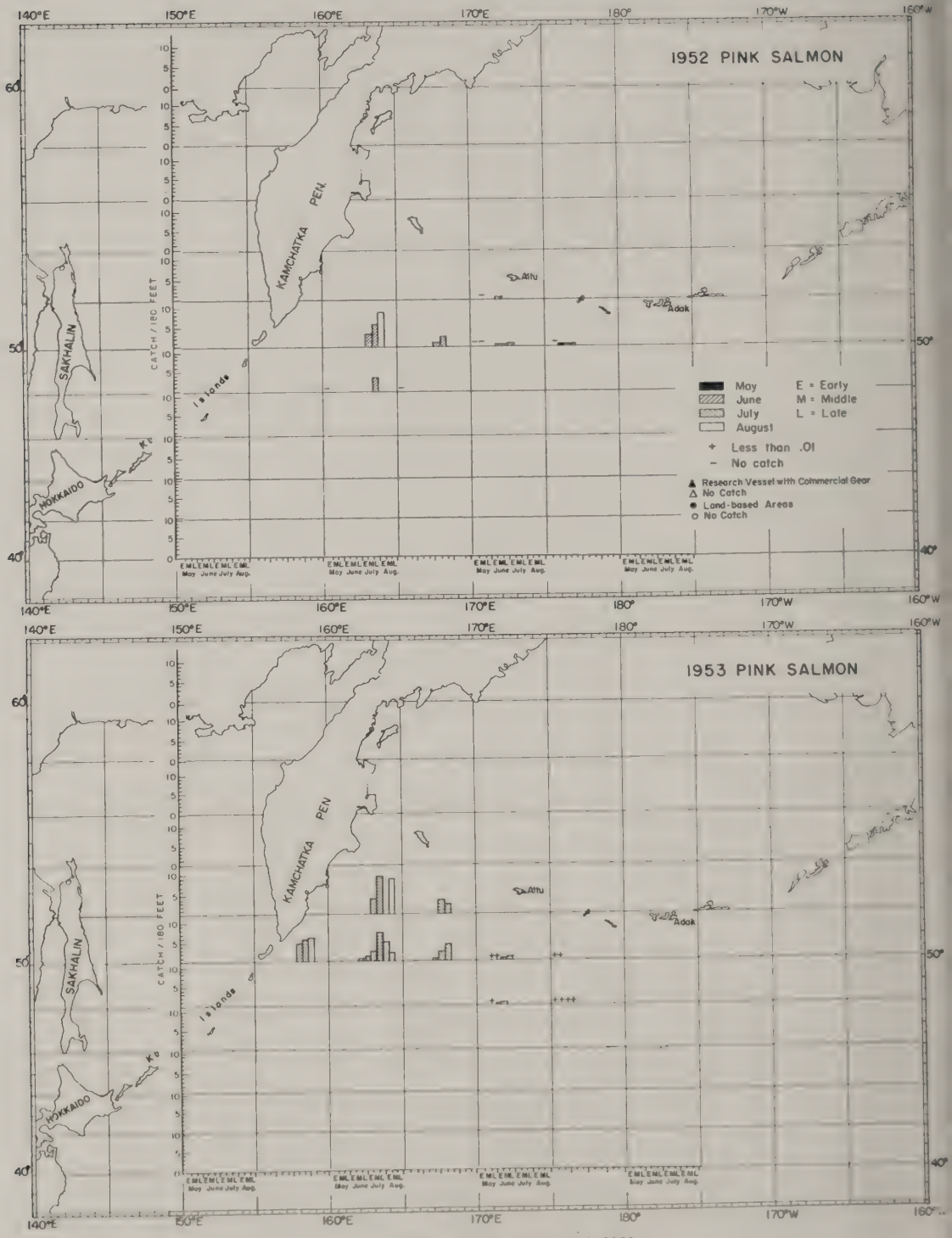
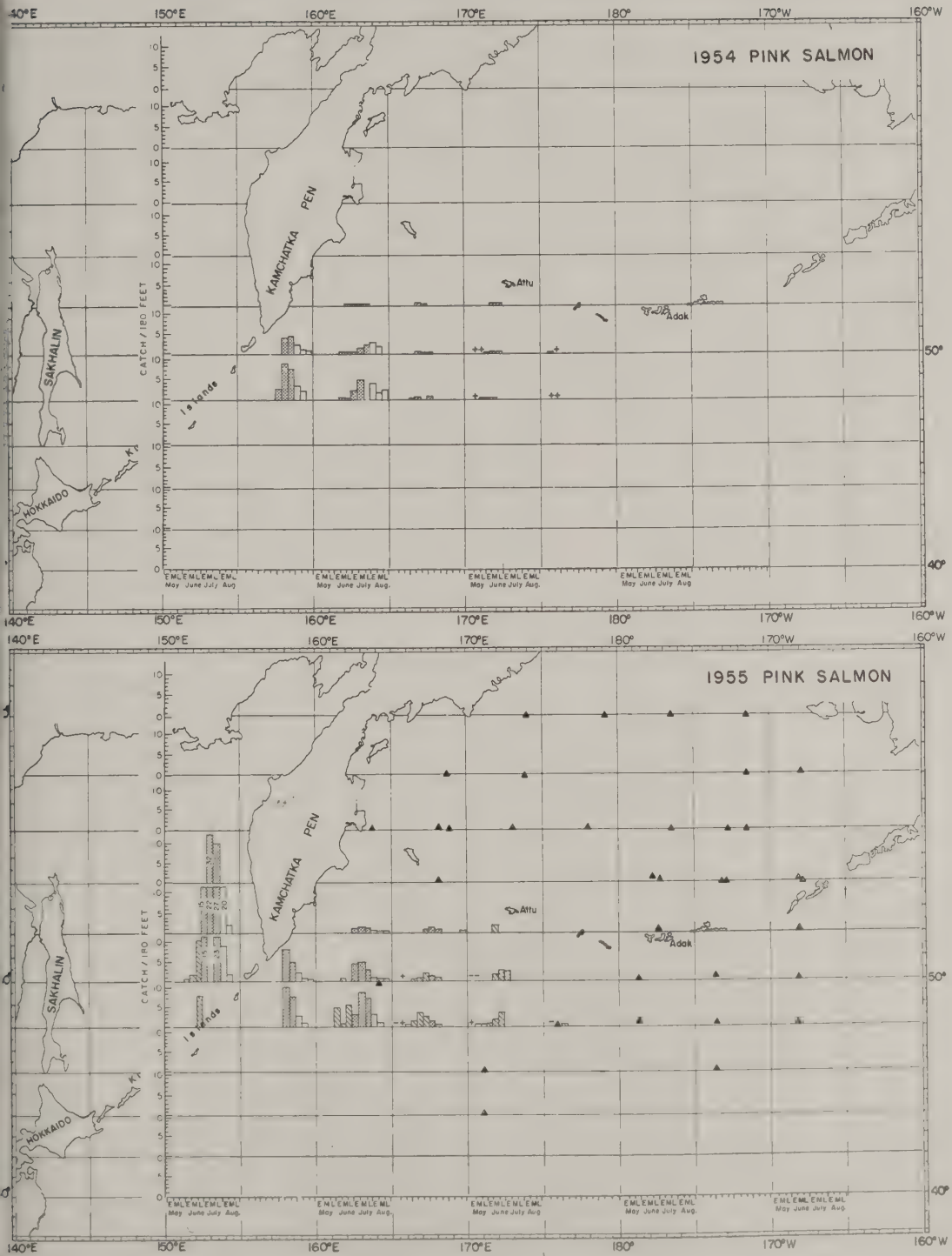


APPENDIX FIGURE D-3. Pink, 1952–1960.



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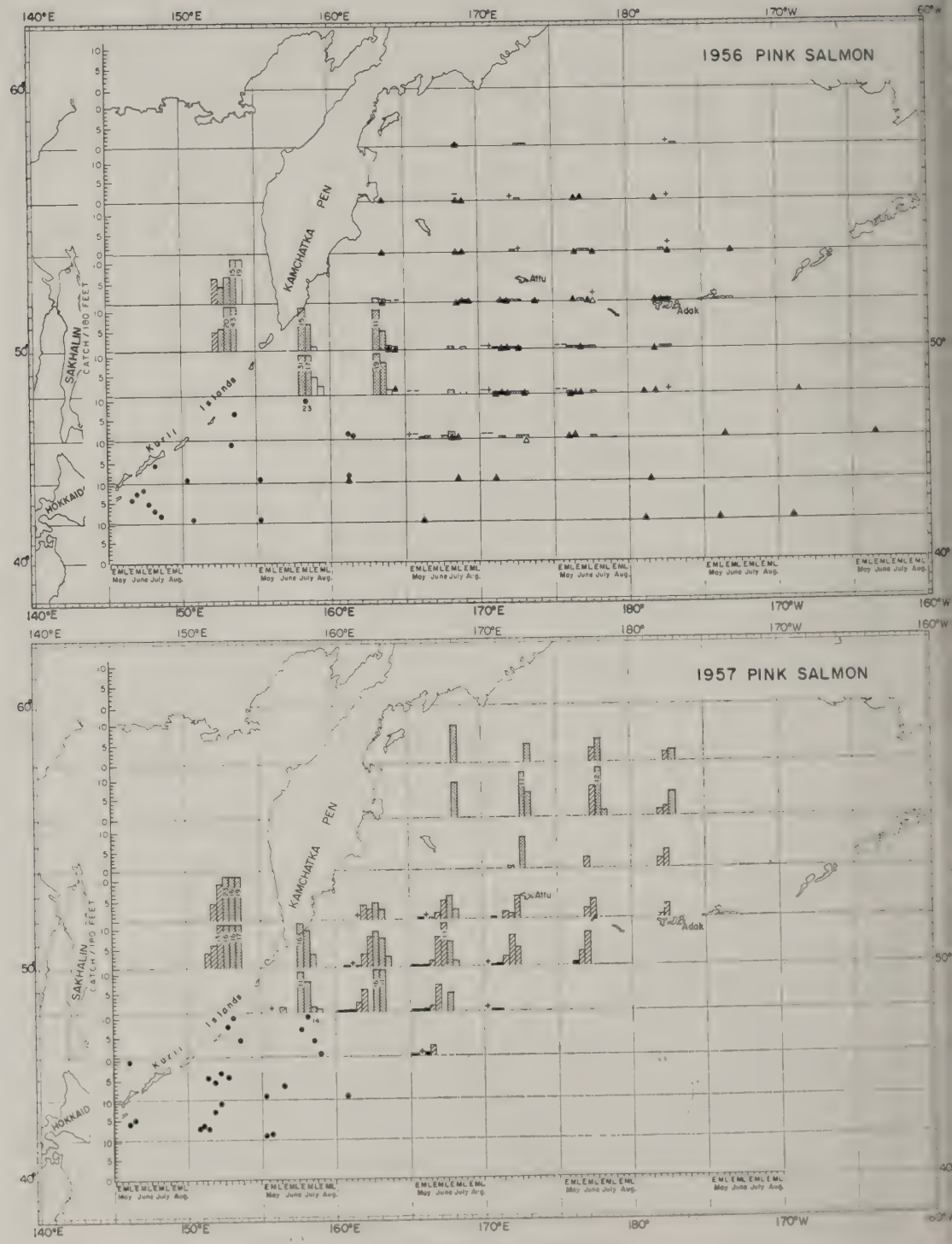

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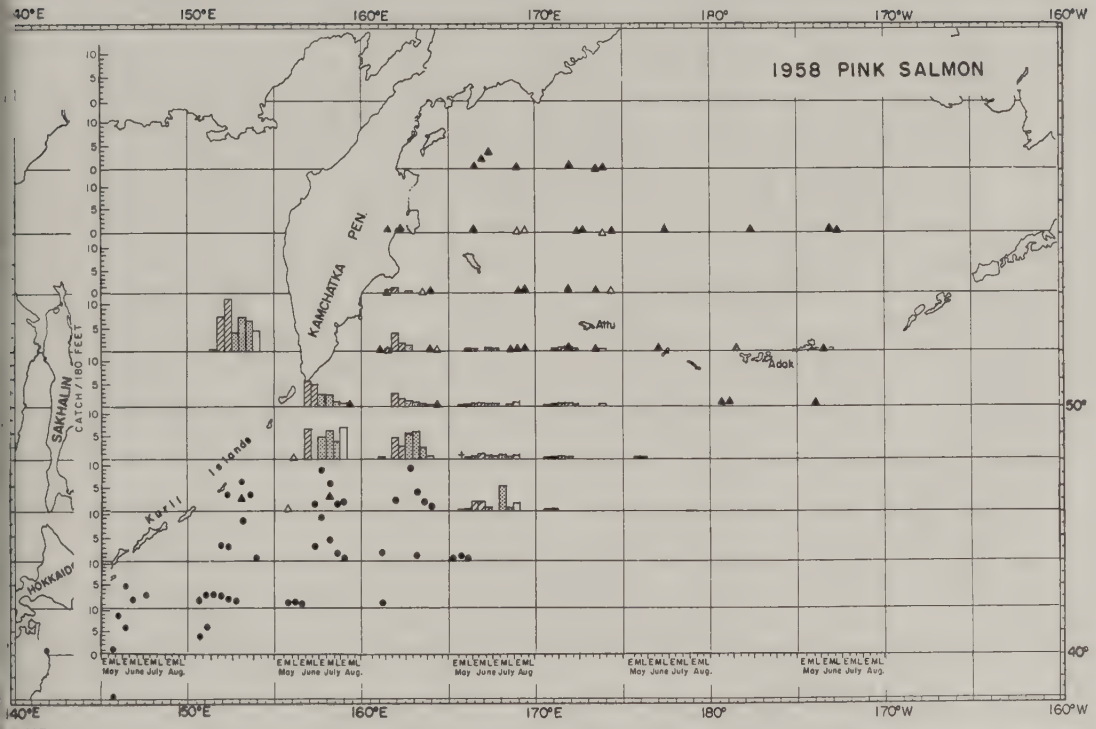

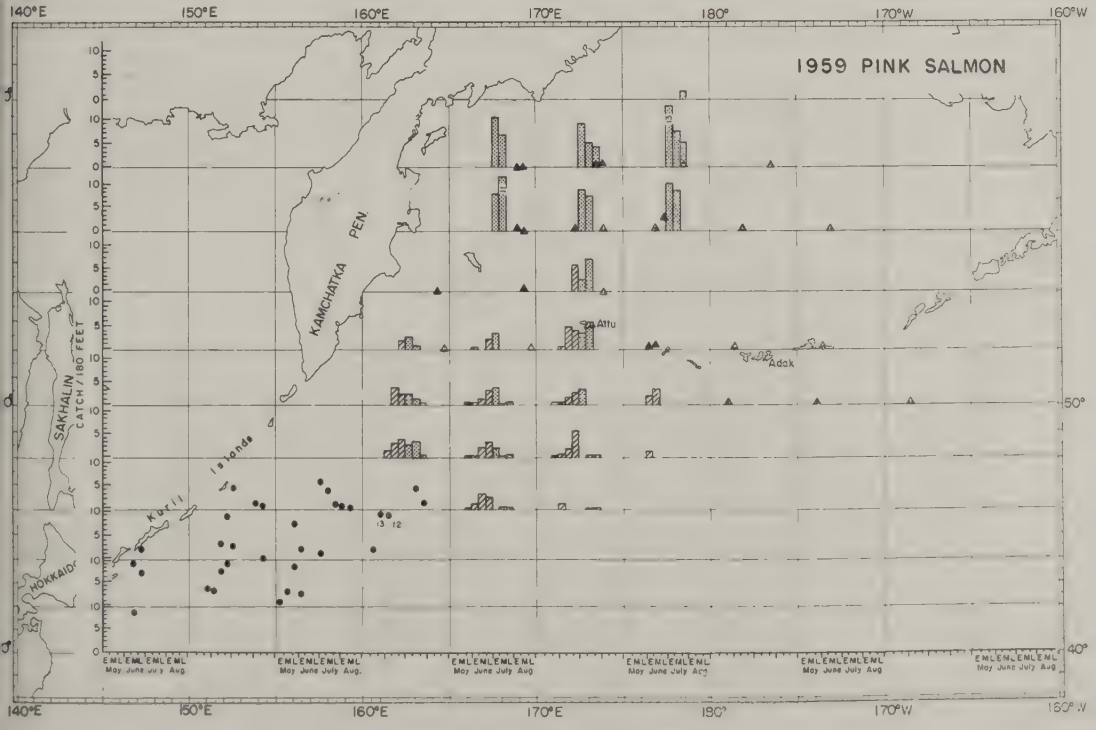

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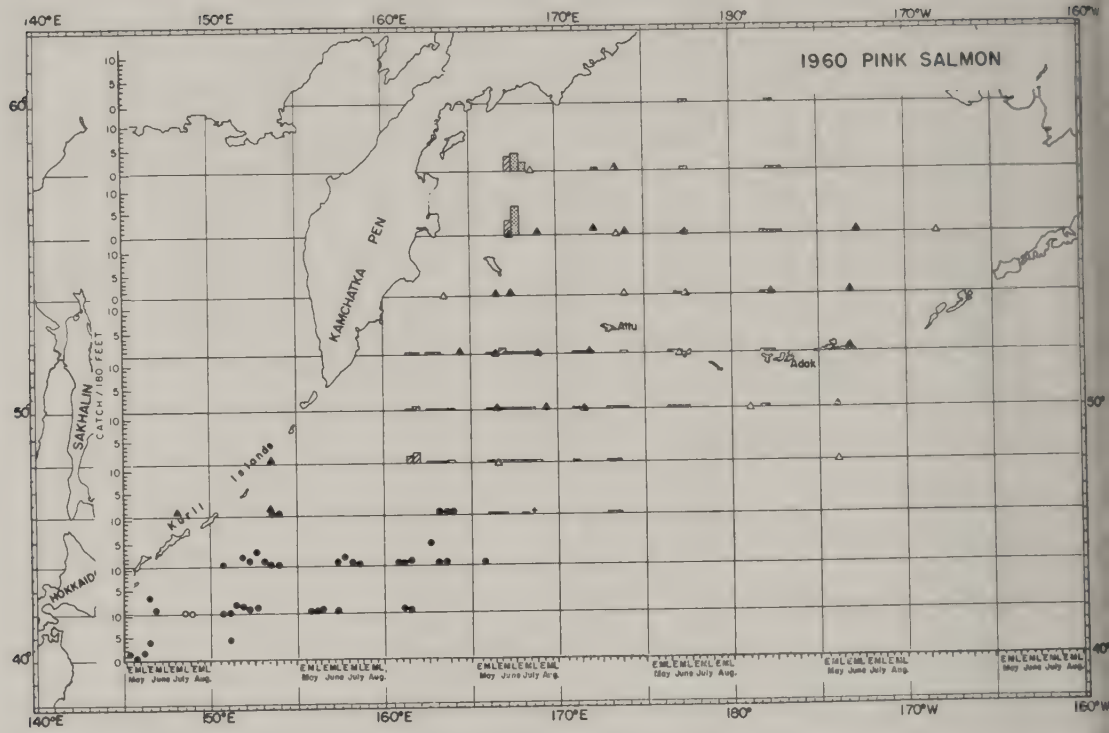

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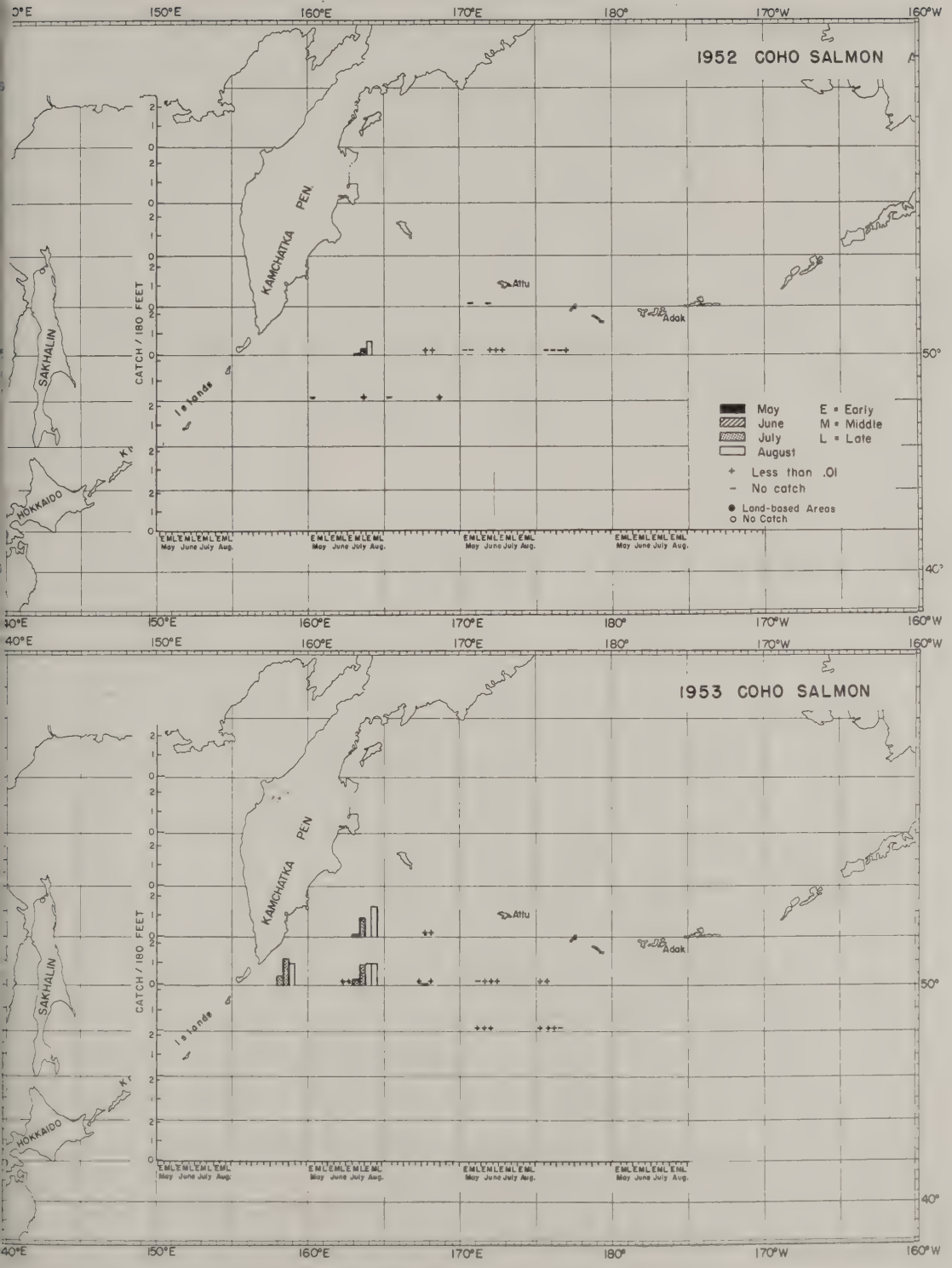
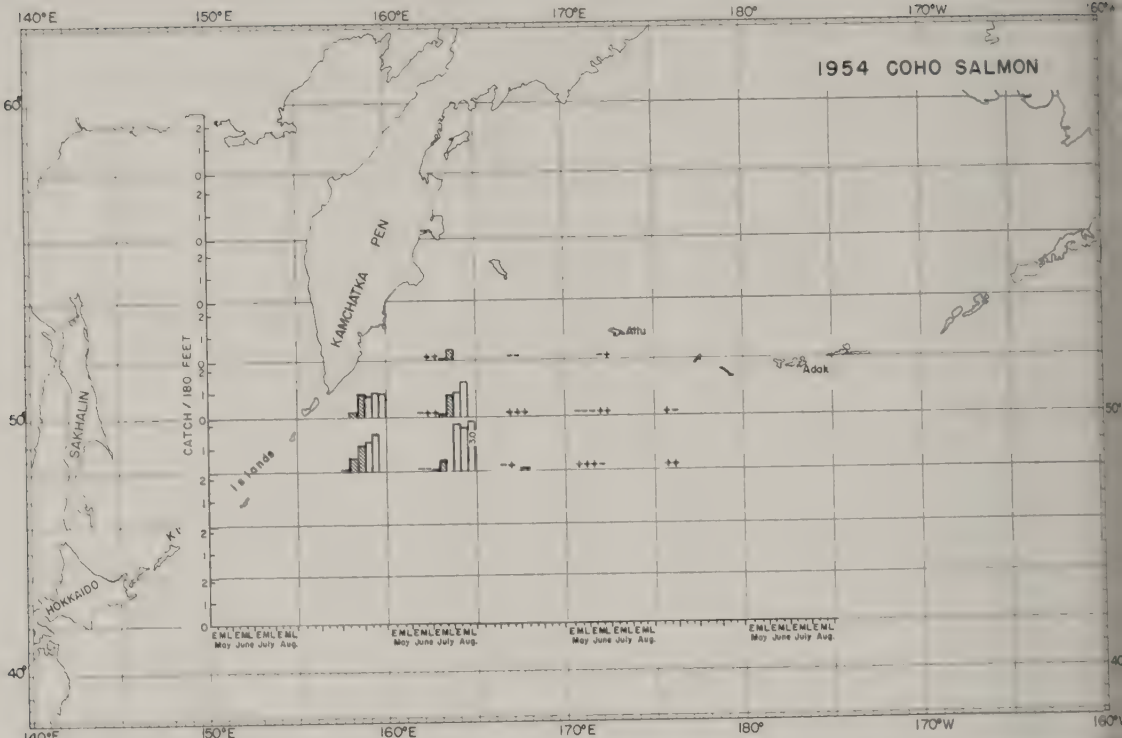
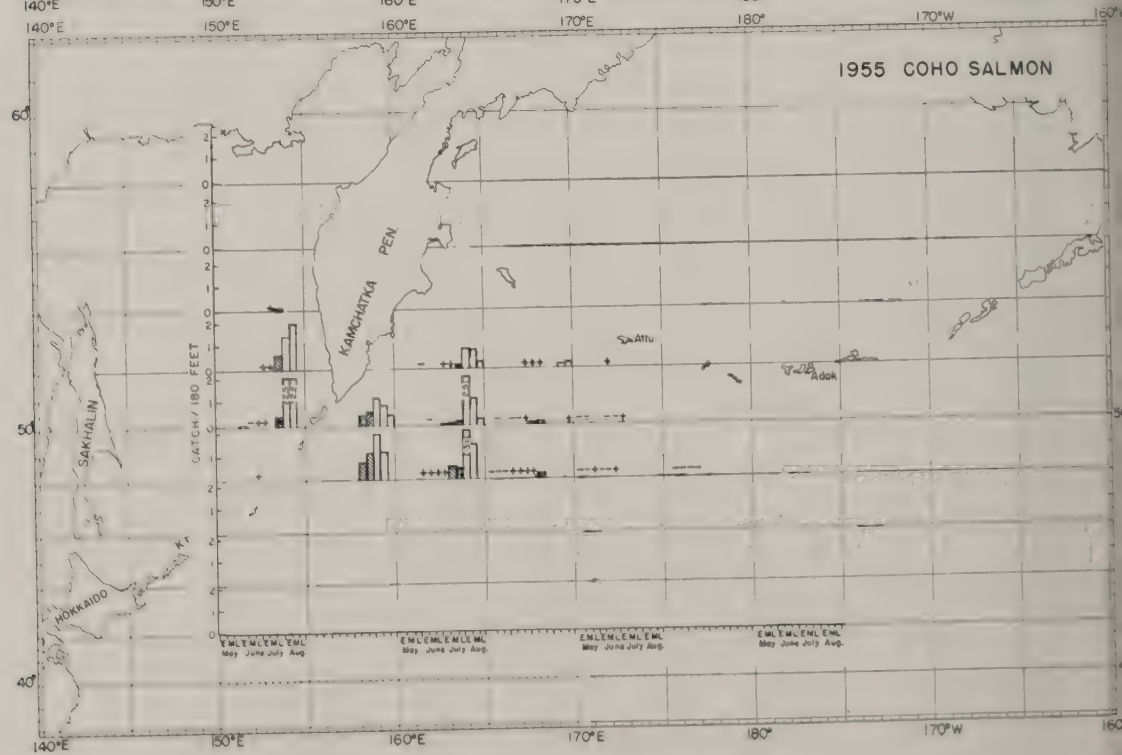


Appendix Figure D-4. Coho, 1952–1960.





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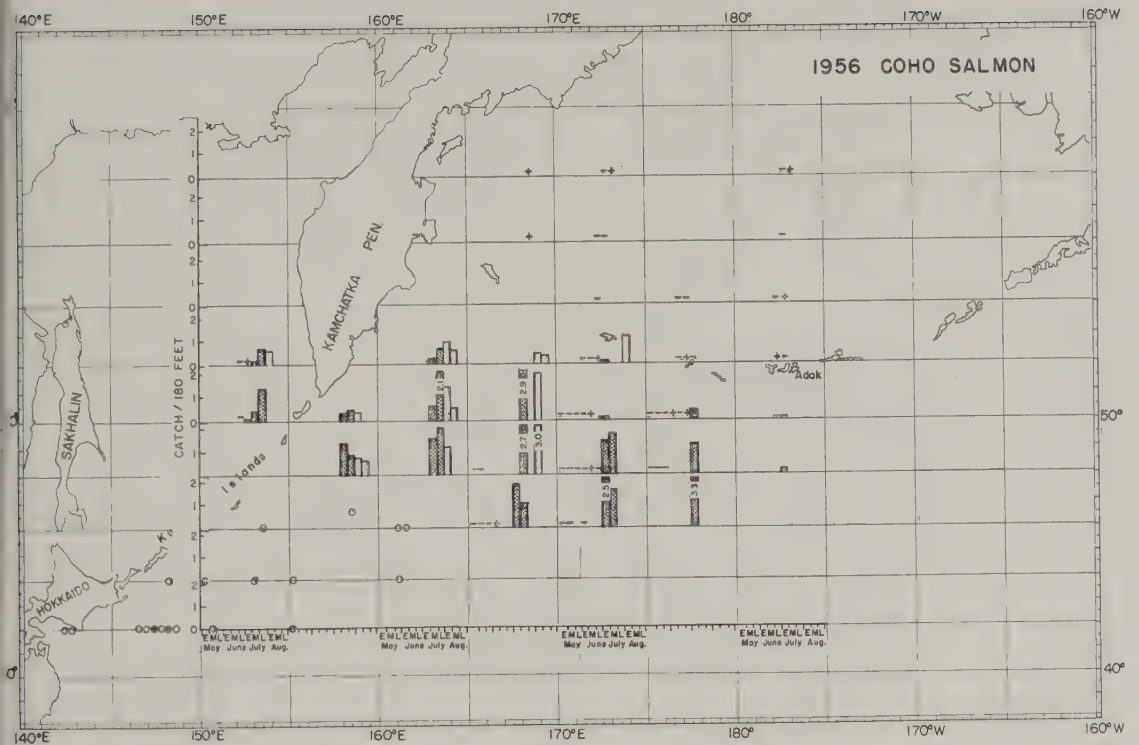

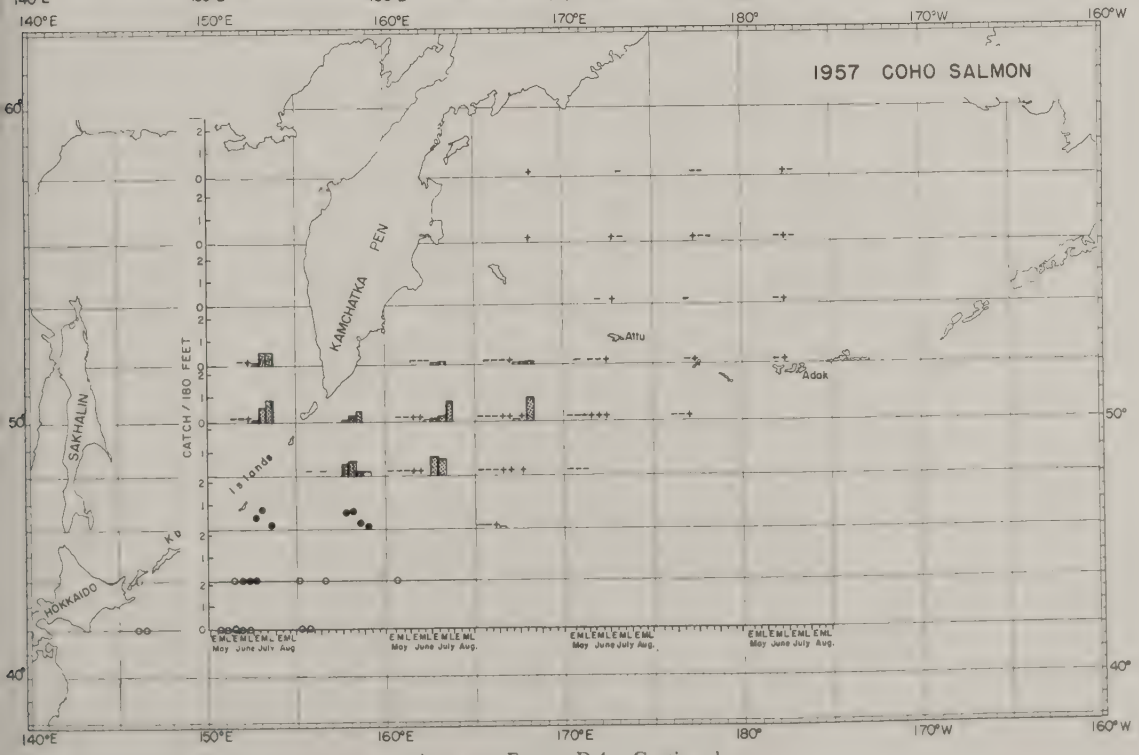

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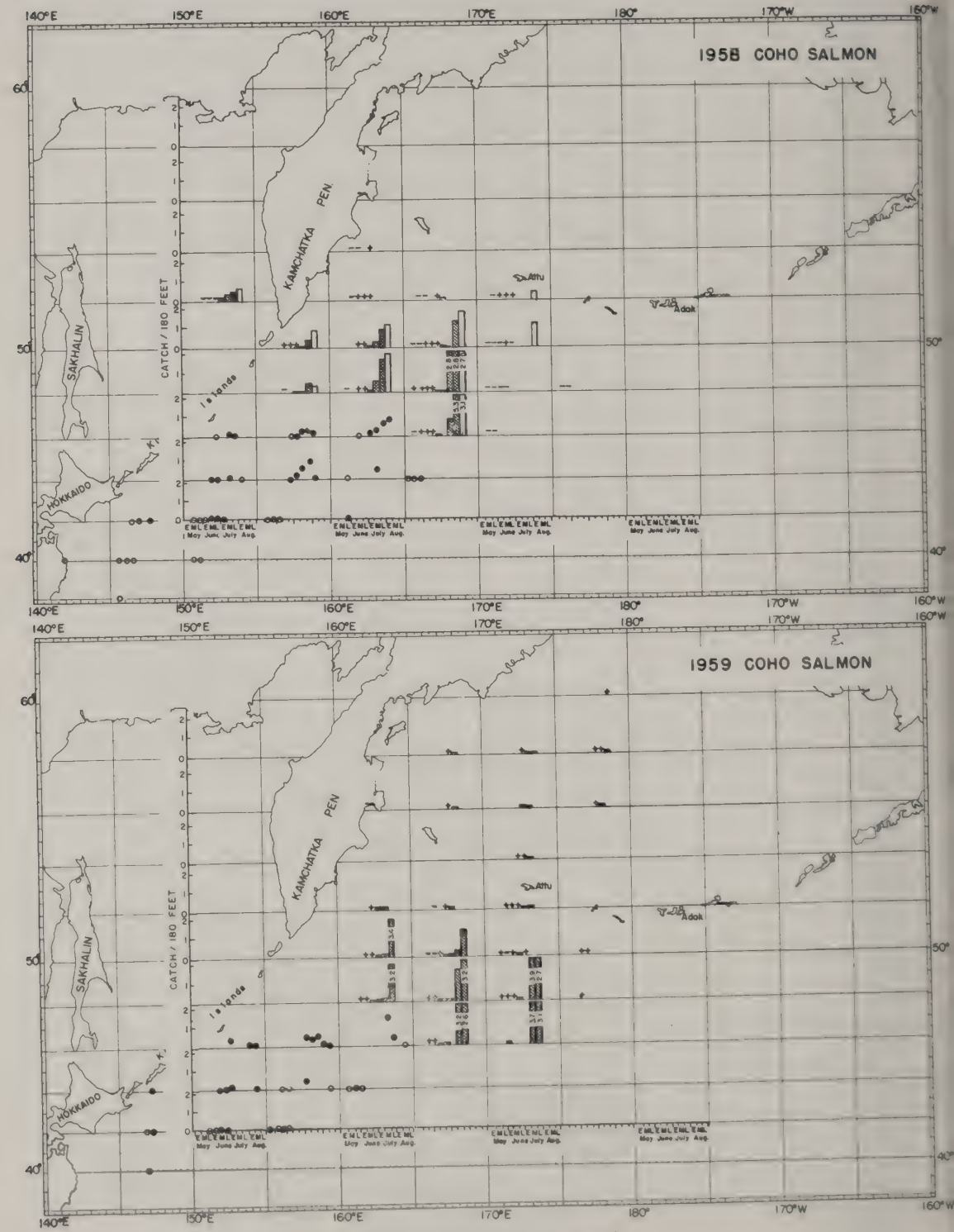

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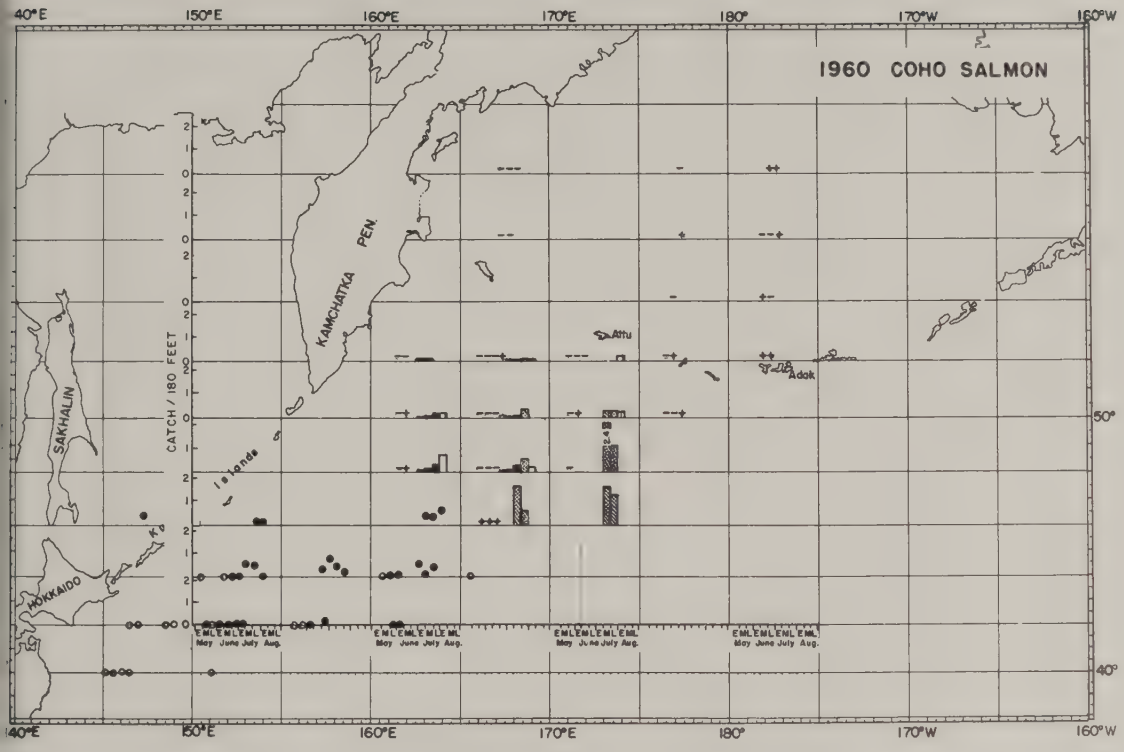

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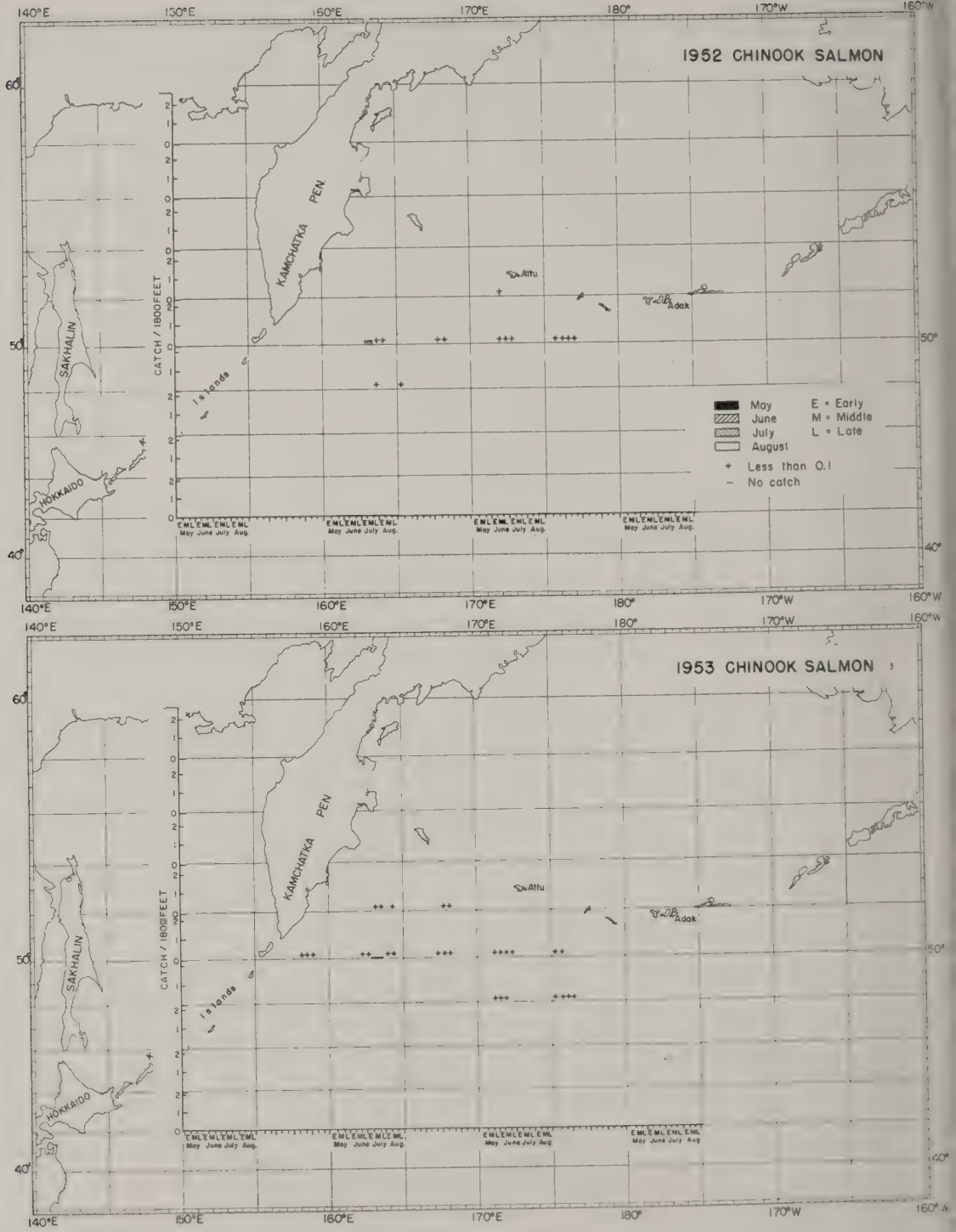
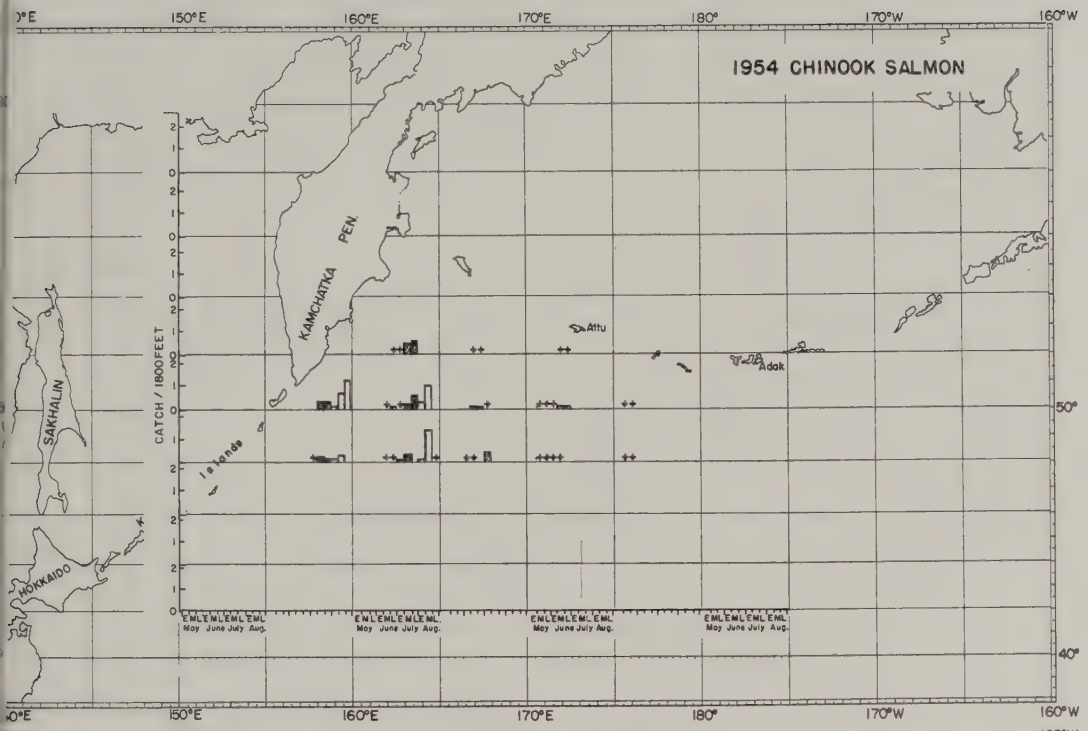
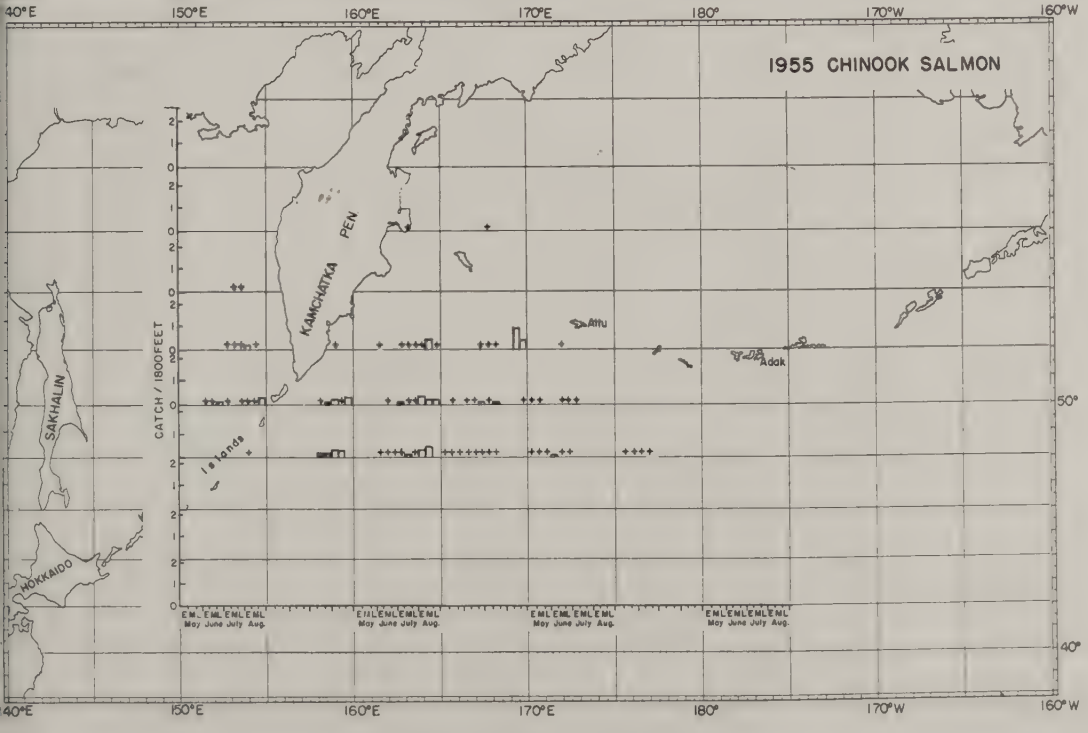


Appendix Figure D-5. Chinook, 1952–1960.





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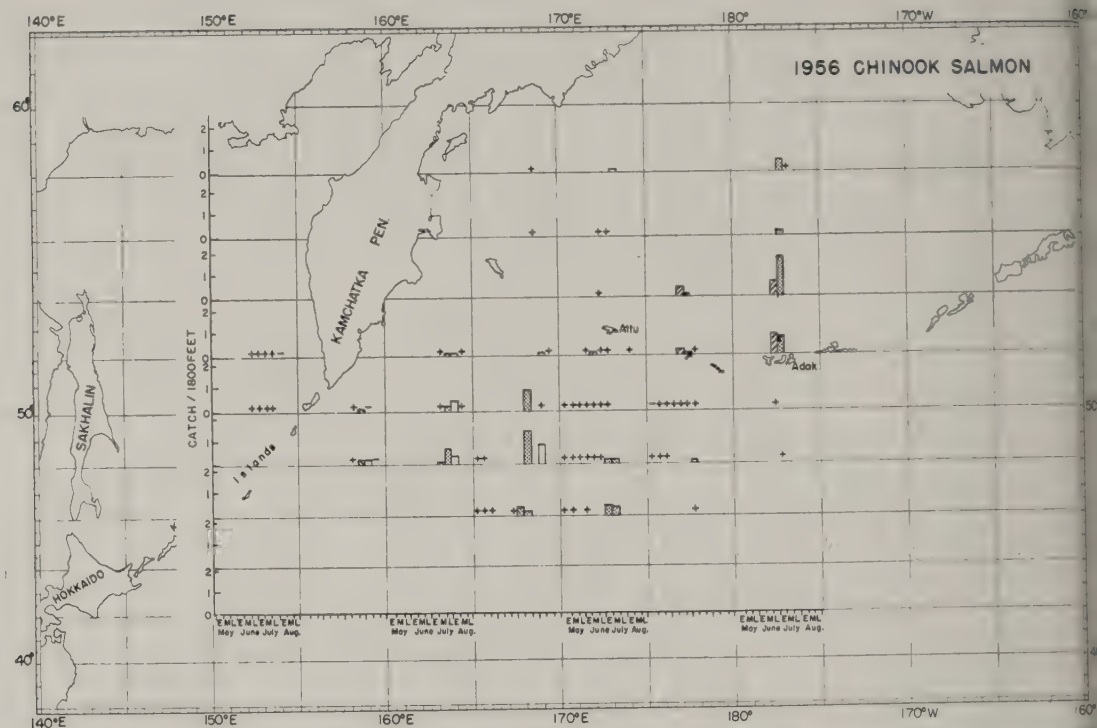

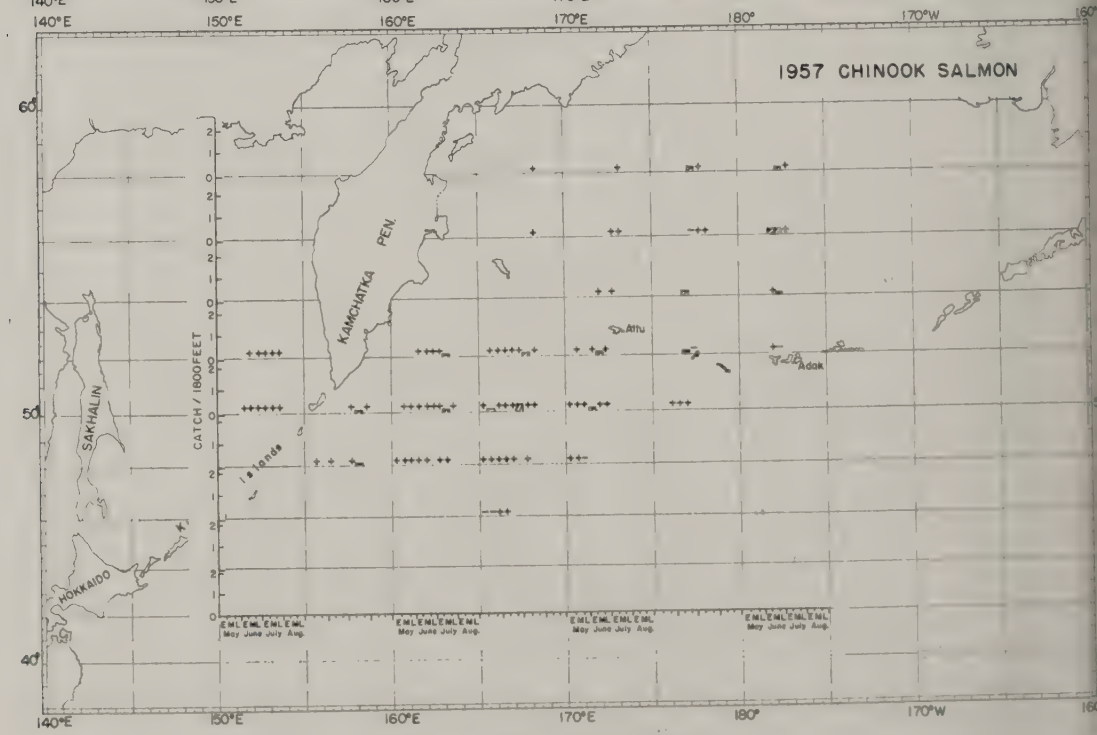

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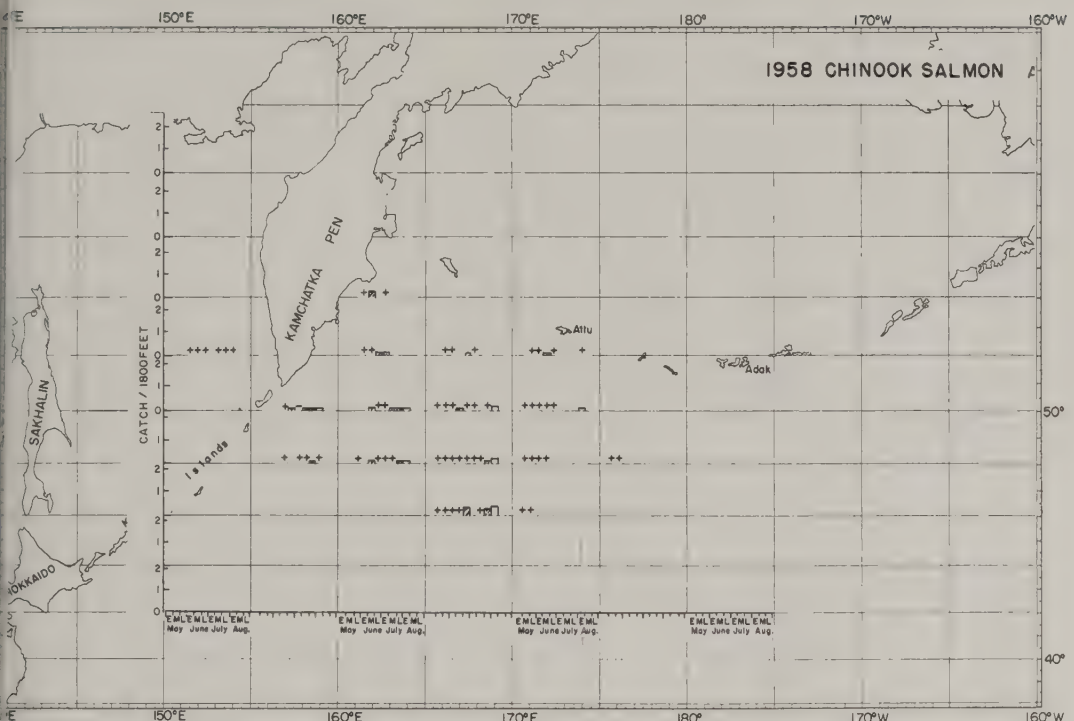

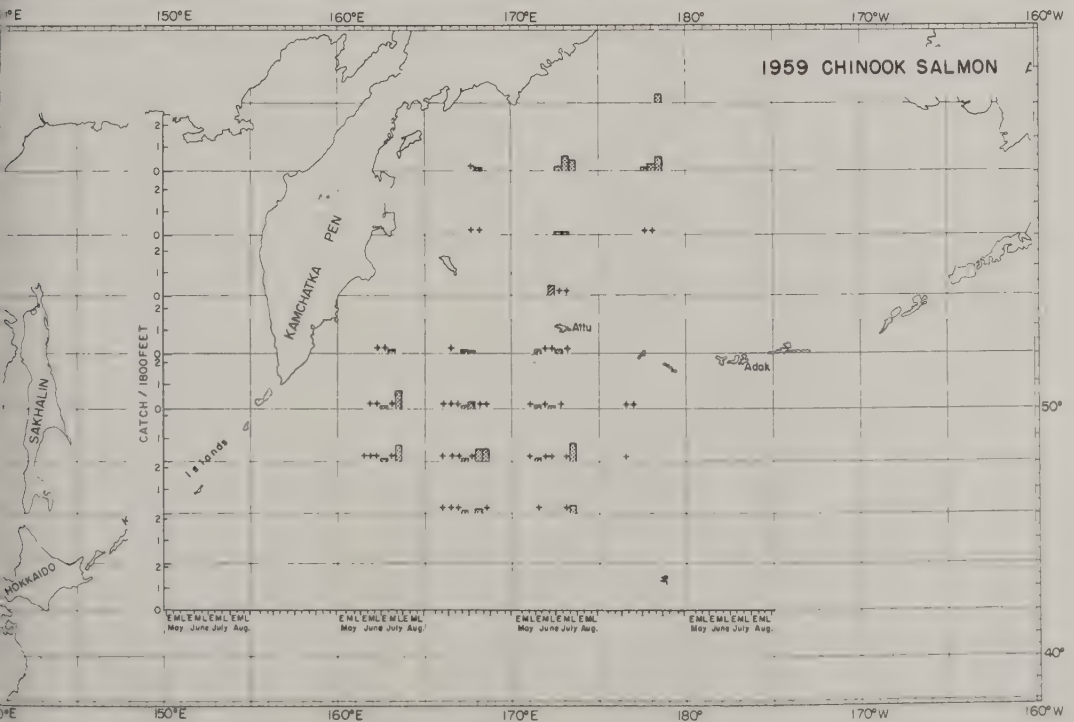

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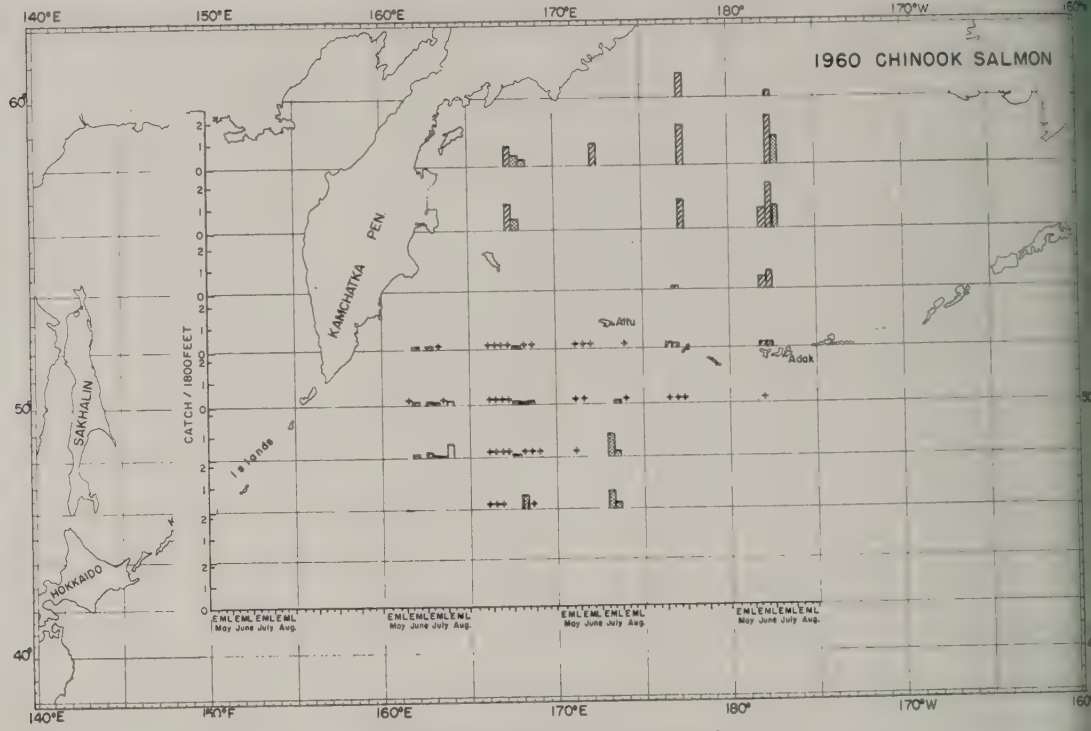

Appendix Figure D-5. Continued.

REPRINTED FROM PROCEEDINGS OF THE GOVERNOR'S CONFERENCE ON SCIENCE AND TECHNOLOGY, STATE OF HAWAII, JANUARY 26-30, 1965, P.67-72.

OCEANOGRAPHIC INSTRUMENTATION AND HAWAIIAN FISHERIES

by
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Hawaii Area Director
U. S. Bureau of Commercial Fisheries

Speculating about the future as we are doing is always exciting. The more freedom we grant ourselves, the greater the excitement and, perhaps, the less realistic our results. Put another way, the shorter the period to which we restrict ourselves the more likely will our results be of immediate application. I should like to restrict my speculations to the next 10 years.

Although Federal expenditures in oceanography are small compared to some other fields, such as space exploration or health, they have experienced a rapid growth in recent years. They rose from 24 million dollars in 1958 to 124 million dollars in 1963. The latter figure, incidentally, is about one per cent of Federal support for all scientific fields and disciplines. The Interagency Committee on Oceanography estimated in 1963 that growth should average somewhat more than 10 per cent per year, that the total annual Federal expenditure for oceanography should be about 350 million dollars by 1972, and that the growth over this period would be at somewhat greater rate than that experienced by Federal support of science in general (ICO, 1963). The National Academy of Sciences Committee on Oceanography has estimated that these expenditures could be an essential component in saving 3 billion dollars per year through improved practices and in adding another 3 billion dollars per year in new production (NAS, 1964).

Oceanography includes all fields of inquiry which impinge on the ocean in one way or another. It is obviously impossible, during this Conference, to discuss instrumentation discipline by discipline. It is possible, however, to consider oceanographic observations and collections as being of two sorts; those that require the presence of a human being and those that do not. Those that require the presence of a human being generally also require some kind of a vehicle, such as a surface ship, a submarine, or an airplane. The technology of airplanes and surface ships is already such that any developments in the next decade are not likely to have a major impact on oceanography. The technology of submarines has hardly been exploited for research purposes and I will return to this subject shortly. Major advances in activities requiring the presence of human beings, then, will most likely be of four kinds:
(1) Those in which there is advance in the instrumentation available to make observations which we might by now consider to be traditional or conventional. An example of this kind of advance is the salinity-temperature-depth probe, which gives much more rapidly and continuously the information now acquired through the laborious use of Nansen bottles and reversing thermometers.
(2) Those in which there is advance in instrumentation that will provide

entirely new ways of looking at the ocean. (3) Those which affect the speed with which data can be processed and the kinds of analyses which can be made; i.e., automatic data processing (ADP). (4) Those which affect the kinds of observations we make. Here I refer to the ability to resist the conventional ways of thinking, so that we can attack specific problems through the substitution of a different set of observations or perhaps even by the substitution of a different set of problems. In the long run, major advances are most likely to be of this nature. For the immediate future, the greatest advances are most likely to be those associated with the use of ADP and computer techniques. Advances in instrumentation are most likely to be in the nature of refinements rather than in entirely new ways in which to look at the ocean, although one can always hope to be surprised.

Observations which can be made without the presence of human beings require buoys, moored or free-floating, at surface or subsurface levels, or unmanned vehicles such as drone planes, satellites, or submarines. Buoys may range from simple drift bottles to highly sophisticated electronic instruments. There has been much recent interest in the latter and they are probably at or approaching the stage of shelf hardware. Once ready for general use, they will provide some kinds of information not available by any other means, but, obviously, will be of little use in the study of many problems. The technology of unmanned planes and satellites, and perhaps submarines, is already well advanced beyond the ability of oceanography to make full or even substantial use of them. Fairly, it might be said here that oceanography needs to catch up with instrumentation.

So far I have been referring primarily to instrumentation with which to attack physical and chemical problems. Once we get into biological problems, however, the situation is much more complicated. Consider the relatively simple problem of sampling in a representative manner animals which are distributed in three dimensions, which may regularly vary their distribution over periods that range in length at least from 24 hours to one year, and which reproduce, grow, and die in rates that vary over time and space. Oceanographic instrumentation for biological problems, in general, is sadly deficient.

Before considering a specific area of oceanography which has the potential of considerable economic growth for Hawaii, the general potential of oceanography for Hawaii can be summarized by considering what Hawaii has to offer oceanography. Hawaii has two things to offer, location and talent. The oceanographic advantages of the location of Hawaii include:

1. It is centrally located in the largest ocean. Deep water is close at hand, as is the high seas environment away from the influence of continental land masses. Major features of circulation, such as the equatorial current system, are relatively near.

2. There is a wide variety of animals available for experimental purposes, ranging from creatures of the coral reef to high seas pelagic animals such as tunas, which now can be maintained in captivity.

3. It is in an area that is well known oceanographically, for oceanography is no stranger to Hawaii. You may not realize that more oceanographic cruises have put forth from Hawaii than any of the other 49 states, except 2 or perhaps 3. On one of these cruises, incidentally, the equatorial undercurrent, or Cromwell Current, was discovered. While these cruises, primarily carried out by the Bureau of Commercial Fisheries, have ranged from the Aleutians to the Society Islands and from New Caledonia to the Americas, many of them have been concentrated in the area around Hawaii. This area, perhaps about 2 million square miles, is at least as well known as any comparable area anywhere. It is so well known that studies have passed beyond those of steady state conditions and are now concentrating on dynamic pro-ce cesses.

The oceanographic advantages of the talent of Hawaii are:

1. There is in Hawaii a considerable collection of oceanographic talent, primarily at the University of Hawaii and the Bureau of Commercial Fisheries Biological Laboratory, spread over a wide variety of disciplines. These scientists generate the ideas and produce the results upon which commercial applications must eventually be based. Experience elsewhere has shown that industry tends to settle around such collections of talent, perhaps after they attain some critical mass. Although, as has been pointed out by previous speakers, one does not necessarily follow the other.

2. Within the scientific community, a collection of talent makes it easier to attract additional talent and facilities. I believe we have already seen this principle beginning to operate in Hawaii. Active development of the Kewalo Oceanographic Center will provide a focal point for such growth and will probably hasten the process.

Let us turn now from this general consideration to examination of a particular set of oceanographic problems and associated instrumentation problems, the solution of which holds economic potential for Hawaii. I refer to the problem of developing Hawaii as the center of a major tuna fishery. This particular problem was selected, not only because of economic potential, but also because it demonstrates some of the instrumentation needs in biology.

As you know, fishing is a form of hunting, generally carried out by the use of nets or hook and line. These kinds of gear are operated either at or near the surface or on or near the bottom. Some midwater gear has been developed, but is not in widespread use, unless the Japanese tuna longline

be considered a form of midwater gear. What is needed for American fishermen is an increase in efficiency of existing forms of gear, or completely new kinds of gear of high efficiency, so that they will be able to compete with foreign fishermen.

The existing fisheries of Hawaii are very modest indeed. The two major fisheries are those for skipjack tuna, carried out by pole and line gear with the use of live bait, which produces about 5,000 tons per year, and for yellowfin and bigeye tuna, carried out by longline gear, which produces about 2,000 tons per year. Yet we know that Hawaii is located in the midst of considerable fishery resources. The Bureau's Honolulu Laboratory has demonstrated the existence of skipjack resources in the Marquesas Islands area, of yellowfin tuna in the equatorial region, and of albacore tuna to the north of Hawaii. We know that within a 1,500-mile radius of Hawaii, Japanese fishermen catch perhaps as much as 5 times the annual landings of Hawaiian fishermen. Hawaiian longline fishermen, who normally fish very close to the islands, have recently been encouraged to fish as far away as 300-400 miles. In some seasons, at least, their catch rate has gone up by a factor of 5, time at sea has been shortened, and quality of product has been improved. These boats, however, are now operating at the limits of their range. Thus, a major part of this particular problem is not one of providing new knowledge, but rather one of whether or not it is economically feasible to construct longer range boats and take advantage of existing knowledge. The answer to this is that it appears to be likely enough to be worth testing, considering the fact that vessel construction subsidies now available (P.L. 88-498) reduce the competitive advantage of foreign fishermen. It has been proposed that the Federal Government provide a prototype vessel which could test the economic feasibility of this fishery.

Resources of much greater potential exist in the high seas populations of skipjack tunas and the smaller sizes of yellowfin and bigeye tunas, which are not taken by longline gear. It has been estimated that these resources could yield an annual catch of perhaps 200,000 tons. Suppose that half of this amount were taken by a Hawaii-based fishery. This would mean a gross return to the fishermen of something like 20 million dollars annually and a gross return to the processors of about 50 million dollars annually. Such a fishery would require a fleet of about 70 boats with about 1,000 fishermen, would require expansion of processing facilities by a factor of about 8, and could provide direct additional employment on shore of about 2,200 people, exclusive of ancillary businesses such as ice plants, ships chandlers, fuel docks, and shipyards. Furthermore, this general kind of industry need not necessarily be based on Oahu, an important point in the state-wide economic development of Hawaii.

There is not now such an industry primarily because of a lack of information. We know that the resources exist, we know the general -- but not

the specific -- details of their geographical distribution, we know that they generally occur beneath the surface, and we suspect that they occur in schools. We do not know where major concentrations occur, if such exist, we do not know their depth distribution and how this may vary, and we do not know certainly that the fish occur in schools.

These are imposing oceanographic problems and they involve imposing instrumentation requirements. These problems are being attacked through experimental studies of tuna in captivity and through observations at sea. From the studies of skipjack in captivity it has been found, for example, that non-feeding fish have a color pattern of horizontal stripes. When the fish are feeding, or are about to feed, this changes to a pattern of vertical bars. A fish exhibiting the barred pattern affects the behavior of other fish within visual range. It is not beyond the realm of possibility that this feature of behavior, or some other feature involving olfactory or auditory systems, could be employed to increase the efficiency of fishing.

By observing the occurrence of bird flocks, and taking advantage of the interdependence of birds and tunas through the small fishes on which they both feed, we know that tunas do occur at the surface at some times and places in the central Pacific. This suggests that some form of existing surface gear may prove to be useful at these times and places.

For the most part, however, these resources are below the surface. In order to learn where these fish are and how they are behaving when they are below the surface, we must somehow, directly or indirectly, place an observer in their vicinity. A first step in this direction is the use of underwater viewing ports on the research vessels "Charles H. Gilbert" and "Townsend Cromwell." Through the use of these ports we have been able to learn much about tuna behavior, but only when they are immediately below the surface. A logical extension of this approach is to use viewing ports on a submarine. We have recently completed a feasibility study which indicates that a research submarine could be built with the requisite characteristics of speed, endurance, and maneuverability to enable the subsurface study of tunas.

Also, the study of subsurface tunas must be approached indirectly through the use of sonar. A present state of the art sonar, with a range of 2,000 yards, will be installed on the "Townsend Cromwell" early in 1966 as a significant first step in this direction. However, an appropriate sonar at least as sophisticated as the most advanced military model needs to be developed for this research.

As information on the distribution and behavior of the subsurface tuna resources of the central Pacific accrues from these different studies,

then it will be possible to consider the gear and vessel design necessary to make the harvesting of these resources economically feasible. Given adequate effort, this stage could be completed in the next decade.

In summary, Hawaii has the assets of location and talent to offer oceanography. A specific example of how oceanographic studies can directly benefit the economy of Hawaii is the study of subsurface tunas, leading to the development of the tuna resources of the central Pacific.

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Reprinted from Limnology and Oceanography
Vol. 10, No. 2, April 1965
pp. 288–290

STABILIZING THE AMMONIA-NITROGEN CONTENT OF ESTUARINE AND COASTAL WATERS BY FREEZING

by Kenneth T. Marvin and Raphael R. Proctor, Jr.

Stabilizing the Ammonia–Nitrogen Content of Estuarine and Coastal Waters by Freezing[1]

In 1950, the Bureau of Commercial Fisheries Biological Laboratory at Galveston, Texas, began to investigate methods of stabilizing the chemical composition of seawater samples. The object was to find a noncontaminating means of storing perishable marine and estuarine water samples gathered for chemical analysis. Such a procedure would eliminate the need for immediate analysis and allow storage until the facilities of the shore-based laboratory could be employed.

Since undertaking the investigation, it has been shown that many of the constituents of seawater are effectively stabilized if the samples are placed in cold storage (below freezing) as soon as possible following collection. Collier and Marvin (1953) demonstrated that the concentration of inorganic and organic phosphate in frozen seawater samples remains unchanged for long periods of time. May's (1960) investigation of the cold-storage technique showed that the concentration of carbohydrate in frozen seawater remains stable for about 7 weeks, but that significant changes then begin to occur. The technique also proved useful in the storage of seawater samples collected for nitrite analysis (Proctor 1962).

This paper presents results showing that ammonia-nitrogen (NH_3-N) concentration in estuarine and coastal waters, normally containing many times the NH_3-N concentration of open seawater, can also be stabilized by freezing.

Fig. 1 depicts variation with time in the NH_3-N content of estuarine water analyzed under different experimental conditions. All NH_3-N estimates were made using Treadwell's Nessler reagent, recommended for seawater analyses by Wirth and Robinson (1933). Direct Nesslerization was possible by following the procedure of Wattenberg (1931). The curves in Fig. 1A represent the NH_3-N content of a 20-liter sample taken from a small lagoon located at the east end of Galveston Island. At the beginning of the experiment, the NH_3-N content was very low. The sample was therefore fortified with $(NH_4)_2SO_4$ to the NH_3-N level shown, so that variation with time of the NH_3-N concentration could be more easily followed. The sample was fil-

[1] Contribution No. 185, Bureau of Commercial Fisheries Biological Laboratory, Galveston, Texas.

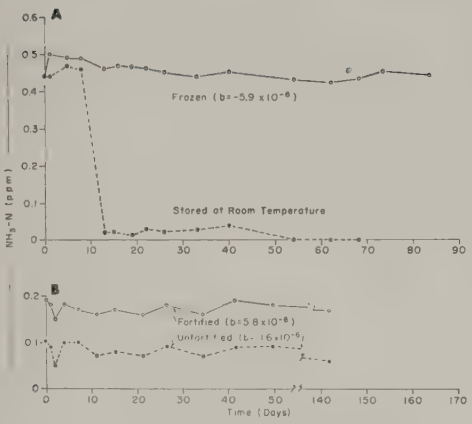

FIG. 1. A. Comparison of NH_3-N stability in frozen and unfrozen estuarine water samples. B. Variation due to systematic errors in measuring the NH_3-N content of frozen coastal water samples.

tered to remove particulate matter and then dispensed into 200-mm glass culture tubes with Poly-Seal caps. Half of the 200 subsamples were stored in a freezer at –23C, and the other half in daylight at room temperature. Each point on the trend curves in Fig. 1A is the average of 5 analyses (5 tubes) made at the indicated intervals.

The curves in Fig. 1B show similar data based on a 20-liter sample of coastal water collected near Galveston Island. These curves demonstrate a source of systematic error and also show that the stabilizing effect of freezing on the NH_3-N content of fortified coastal water and non-fortified water is the same. Thus, the use of $(NH_4)_2SO_4$ to fortify the NH_3-N concentration of the samples investigated was warranted (Fig. 1A). In this experiment, only half the original sample was fortified with $(NH_4)_2SO_4$. Both halves were filtered, however, and then subdivided as before and stored in a freezer. Each value on Fig. 1B also represents the average of 5 analyses.

A statistical study of the data shown in Fig. 1B suggested that the precision of each estimated value, in terms of the calculated standard deviations, averaged 0.013 ppm. The conventional "F" test revealed further that the curves' fluctuations are statistically significant. The striking similarity of the curves in Fig. 1B indicates that the observed variation in each is due more to systematic errors or biases within successive sets of subsample measurements than to changes in the NH_3-N concentration of the frozen material. This interpretation is substantiated by the overall rates of change in NH_3-N which are represented by the coefficients of regression of concentration on time (Fig. 1B), and which were virtually nonexistent.

In view of these findings, as well as the obvious changes in unfrozen samples (room-temperature data, Fig. 1A), the authors are of the opinion that the NH_3-N content of those nearshore and estuarine water samples that are high in ammonia-nitrogen compared to open seawater can be fixed satisfactorily prior to measurement by freezing.

The range of NH_3-N concentration in offshore seawater is about 0.005 to 0.05 ppm (Sverdrup, Johnson, and Fleming 1942). These values are too low to be effectively measured by the analytical method employed here. It is possible that minor changes during cold storage of offshore samples could significantly affect the reliability of later measurements of their NH_3-N content. Further research involving open seawater samples and a more precise method of analysis will have to be conducted before it can be determined if the sample treatment described in this paper can be applied to offshore water.

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SALMON OF THE NORTH PACIFIC OCEAN—PART IX
COHO, CHINOOK AND MASU SALMON IN OFFSHORE WATERS

2. CHINOOK SALMON IN OFFSHORE WATERS

by
James E. Mason, Bureau of Commercial Fisheries
Biological Laboratory, Seattle, Washington, January 1964

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Received for publication April 6, 1964. Original, English.
Source: Joint reporting team, Committee on Biology and Research. INPFC Document No. 689.
Bull. 16, Int. North Pac. Fish. Comm., 1965.

INTRODUCTION

The International North Pacific Fisheries Commission has requested the preparation of a joint comprehensive report on the salmon of the North Pacific Ocean and the Bering Sea. Part IX of this comprehensive report deals with coho, chinook and masu salmon in offshore waters. The material to follow comprises the chinook salmon section of Part IX. The objective will be to assess the status of our knowledge concerning the qualitative and quantitative aspects of chinook salmon in offshore waters. Such assessment requires (1) a knowledge of the life history of the young in fresh water and in coastal areas and the distribution of chinook in inshore areas; (2) knowledge of the stocks in North America and in Asia and the distribution and abundance of chinook in offshore waters; and (3) appraisal of these various data to draw conclusions regarding the qualitative and quantitative aspects of the distribution of chinook salmon in offshore waters.

Chinook salmon (*Oncorhynchus tschawytscha*) have been found along the North American coast from the Ventura River in California (Cobb, 1931) north to the Chukchi Sea (Smith, 1960). In Asia, they occur in some large rivers in Hokkaido (Hikita, 1956), in Sakhalin (Shmidt, 1950) and northward at least to the Anadyr River (Kaganovski, 1933). The principal areas of production in Asia are located on the Kamchatka Peninsula. Except for Smith's report (1960), the occurrence of chinook salmon in North American and Asian arctic areas is neither established nor defined in available literature.

Chinook salmon spawn principally in the larger rivers and their tributaries. Although the major North American populations return to the Sacramento,

Columbia, Fraser, Skeena, Nushagak and Yukon Rivers, important runs occur in many other rivers.

Along the North American coast, chinook are taken principally in commercial troll and gillnet fisheries, while important numbers are taken in various sport fisheries. Significant numbers are caught in the Japanese mothership and landbased fisheries and in the coastal and river fisheries of Kamchatka and the Okhotsk Sea. In the period 1954 through 1961, the combined commercial catches of Japan and Russia varied from 96,000 to 250,000 chinook salmon, as compared with 2,456,300 to 3,664,200 for the United States and Canada combined. With the exception of masu salmon, the combined commercial catch of chinook salmon is below that of all other species of Pacific salmon. For example, in 1956, 3,777,000 chinook were caught commercially by Japan, Canada and the United States, as compared to 10,442,000 coho, 29,267,000 sockeye, 34,695,000 chum and 84,949,000 pink salmon. In the same year, an additional 110,000 chinook salmon were taken in the Soviet coastal fisheries and 731,000 in the sport fisheries of Canada and the United States.

LIFE HISTORY

Identification of Runs and Races

Before describing the life history of chinook salmon, definitions of a " run " and a " race ", as used in this paper, should be established, since inherent biological differences are implied which have a direct bearing on time of migration to salt water, perhaps on the extent of marine migration, on time of return to coastal and river areas and on time of spawning.

For purposes here, a " run " is defined as a seasonal appearance of chinook salmon in a coastal or river area, first in small numbers which usually increase rather rapidly to a peak and then decline, with small numbers sometimes continuing to appear for extended periods of time. A " race " is defined as a population of chinook salmon which will spawn in a particular river or tributary at a particular time of the year. A single race may make up all or only part of a run.

Many river systems have more than one run or more than one race of chinook salmon. Each run may include more than one race, each apparently a separate biological entity. Fry (1961), for example, described three runs to the California central valley—a fall run, a spring run and a winter run. Gharrett and Hodges (1950) reported that in coastal Oregon streams a spring run of chinook entered and passed through the fishery, followed by a later fall run. The Columbia River has spring, summer and fall runs of chinook salmon. All spawn in the summer and early fall and winter months, in contrast to the Sacramento River chinook, where the fall run spawns in October to March, the winter run from May to July and the spring run in September and October. The three Columbia River runs of chinook are identifiable in the commercial fisheries of the lower river and estuary (Figure 1, using 1960 for illustration purposes), as well as at the counting stations at Bonneville Dam. These runs also maintain their identity at The Dalles, McNary and Rock Island Dams farther upstream. The chinook counts from The Dalles and McNary Dam are not included in Figure 1, but they may be found in U.S. Army Corps of Engineers (1960).

Many coastal and Puget Sound streams of Washington, and the smaller British Columbia coastal rivers, may have a spring and a fall run similar to those of Oregon (Smoker, 1954). In the Fraser River, chinook may first appear in the commercial

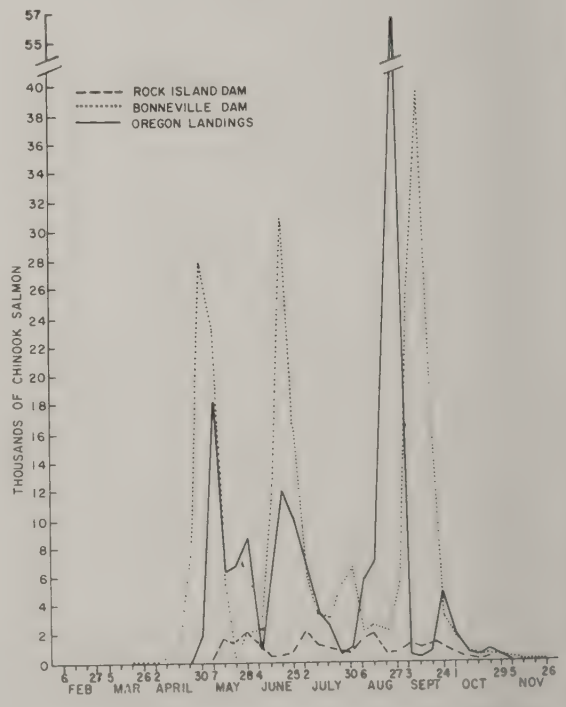

Figure 1. Number of chinook salmon caught by Oregon in the Columbia River and counts of chinook salmon at various dams on the Columbia River, 1960. Data from U.S. Army Corps of Engineers (1960), Zimmer and Davidson (1962) and INPFC Statistical Yearbook 1960.

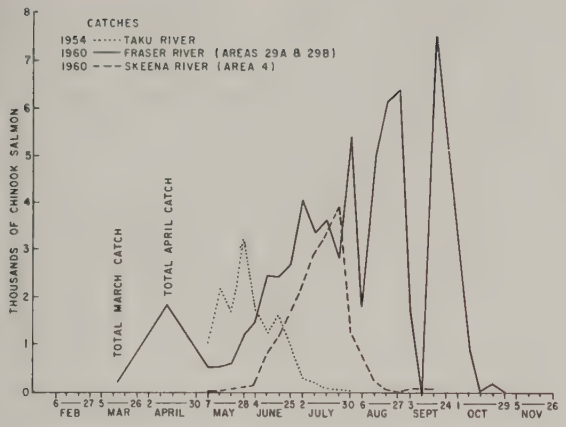

FIGURE 2. Gillnet catches of chinook salmon in the Taku, Skeena and Fraser Rivers. Data from Canada Department of Fisheries (1960) and Weberg and Garceau (1956).

fishery near its mouth as early as January, rising to maximum numbers in August and September and are present into October and even December in some years. Figure 2 shows the gillnet catches near the mouth of the Fraser River for British Columbia statistical areas 29A and 29B for 1960, selected for illustration purposes. The major intra-season declines are attributable to changes in regulations and there is no gross evidence of more than one run. Babcock (1931), on the other hand, stated that the early Fraser River chinook were destined for the headwaters, which implies existence of separate races. Passage of these races through the commercial fishery may overlap to the extent that they are not identified by the gillnet catches alone.

The chinook landings listed in the British Columbia catch statistics are also tabulated in terms of numbers classified as red, white and jacks[1]. The percentages of these three commercial categories in each week's total chinook catch are shown for the Fraser River (statistical areas 29A and 29B) for 1960 in Figure 3. It may be seen that early in the season the catches were almost exclusively of red chinook with only small percentages of white chinook and jacks. The numbers of red chinook declined through the season and rose only slightly near the end of September. The numbers of white chinook rose steadily until July, remained relatively constant through July and August and reached a peak in September. Jack chinook

[1] Separation of red and white chinook is made on the basis of flesh color, red chinook commanding a higher price than white chinook. Jacks are chinook salmon of either flesh color weighing less than six pounds.

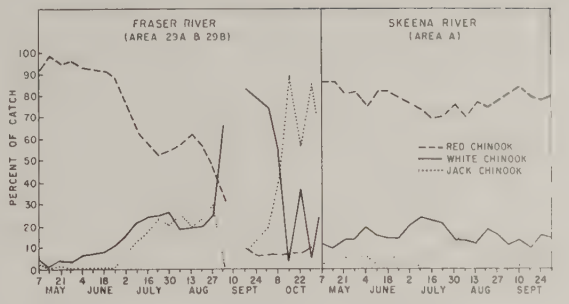

FIGURE 3. Composition (in percent) of weekly catches of chinook salmon in the Fraser and Skeena Rivers in 1960, based on their commercial classification as red, white, or jack chinook (see footnote, page 43). Data from Canada Department of Fisheries (1960).

comprised only a very small proportion of the catch through May and June, with the percentage rising in July and peaking in October. This change in catch composition, when compared to the Fraser River catch curve in Figure 2, is substantial evidence of the existence of different races of chinook within the Fraser River watershed and that the classifications of red, white and jacks may be indices of some possible use in race identification.

The commercial catches of the Skeena and Taku Rivers (Figure 2) were also examined for evidences of more than one run of chinook salmon. For this purpose, the 1960 gillnet catches of statistical area 4 were used for the Skeena River. The Taku River data were taken from Weberg and Garceau (1956) for the year 1954, which was selected as being typical of the published catch data for the years 1945 through 1954. For both the Skeena and Taku Rivers, the commercial catches offer no evidences of more than one chinook salmon run. Also, Parker and Kirkness (1951) recognized only one chinook run in the Taku commercial fishery. It might be noted in Figure 2 that the Taku run reaches a peak earlier than either the Skeena or Fraser run. The Skeena River run is apparently of shorter duration than the Fraser River run and it reaches a peak earlier in the season.

The Skeena River data for percent composition of red, white and jack chinook were plotted in Figure 3 for evidences of changes in racial composition, as were the data for the Fraser River already presented (similar statistics are not available for the Taku). A comparison with Figure 2 again suggests the existence of different races, but not to the degree apparent for the Fraser River.

The rather meager data on weir counts for a number of western Alaskan streams (U.S. Department of

Commerce, 1931–1940), indicate single chinook salmon runs that arrive in late June, July, or August, depending on the particular stream.

Gilbert (1922) stated that the Yukon River run starts around the first of June and is over in about three weeks, the time factor again indicating the presence of only a single run.

The trend indicated in the above examples, ranging from the Sacramento River to the Yukon River, is for a greater number of chinook salmon runs to be found in the rivers to the south, with the number of runs dropping to one to two at mid-latitudes and then to only one in more northern waters. The data also show differences in the time of arrival of chinook salmon runs to various rivers and that the peaks of spring or fall or other runs may vary from river to river. It is also apparent that catch statistics do not always provide enough information to separate races of chinook salmon in the absence of other biological data.

Within a single watershed, a particular run in the commercial fishery may be composed of a number of different races, each bound for a separate tributary. This is particularly true of the major watersheds, such as those of the Sacramento, Columbia and Fraser Rivers. Within their broad geographical boundaries, these watersheds include high altitude streams that depend on melting snows for water, vast arid areas which become extremely hot in the summer and sometimes extremely cold in the winter, and coastal drainages that depend upon seasonal rains for water. The various tributaries originating and flowing through these different climates offer, at one time or another during the course of the year, conditions suitable for migration and spawning of adults, hatching and rearing of young and their feeding and transport to the sea. It is more than coincidence that chinook salmon occur and spawn in particular tributaries at a particular time. It is also reasonable that such things as climate, geography and relationships with other aquatic life have at least some influence on the life history of the species.

The runs described by Fry (1961) in the Sacramento River may also be identified as races, since the fall run usually spawns in the period October to March, the spring run in the following September and October, and the winter run from May to July.

The spring chinook run in the Columbia River commercial fishery includes races destined for such diverse places as some of the tributaries of the Willamette, Snake and Wenatchee Rivers. In the Fraser River, there are spring run races to the Nechako, Bowron, Quesnel and other tributary rivers. In the summer and fall there are late run races in Harrison River and elsewhere. On the Sacramento River, there are spring run races destined for the Keswick Dam area, Battle Creek, Mill Creek and tributaries. A similar list could be made to illustrate summer, fall and winter runs where they occur.

Even in the rivers to the north where a single run is apparent, the racial identities are not lost in the tributaries. The Taku River, for example, has separate races that spawn concurrently in the Nahlin, Nakina and other tributaries. It is unfortunate that,

TABLE 1. Kilograms of chinook salmon landed at Ozuchi, Iwate Prefecture, Honshu, Japan, by 10-day period in 1960 through 1962[1].

10-day period		1960	1961	1962
January		*13.7*	*6.6*	—
	Early	9.8	3.9	—
	Middle	3.9	2.7	—
	Late	—	—	—
February		—	—	—
March		*6.4*	—	*31.9*
	Early	—	—	—
	Middle	5.0	—	10.3
	Late	1.4	—	21.6
April		—	*68.0*	*
	Early	—	—	34.9
	Middle	—	—	*
	Late	—	68.0	*
May		*144.1*	*706.1*	—
	Early	15.8	83.8	—
	Middle	128.3	413.7	—
	Late	—	208.6	—
June		*7.5*	*29.2*	—
	Early	—	13.0	—
	Middle	7.5	8.5	—
	Late	—	7.7	—
July		—	—	—
August		—	—	—
September		—	—	—
October		—	—	—
November		—	*1.7*	—
	Early	—	—	—
	Middle	—	—	—
	Late	—	1.7	—
December		—	*6.3*	—
	Early	—	4.6	—
	Middle	—	—	—
	Late	—	1.7	—

[1] Data provided by Dr. S. Tanaka of the Japanese Fisheries Agency.

* No data available.

at present, there is no method of identifying the various races of chinook salmon until such time as the adults arrive on a particular spawning ground.

There are few data describing the arrival of chinook salmon in Asian waters. Data supplied by Tanaka (Table 1) show that chinook are landed in Ozuchi, in northeastern Honshu, in small quantities from November through January; however, most are landed in the April–May–June period. The chinook caught in the November–January period are apparently immature, as indicated by a 10-day catch of 1.7 kg, which is a small weight even if it consisted of only one fish. An ocean migration and not a spawning migration is indicated for these fish. In describing Okhotsk Sea fisheries, Shmidt (1950) noted that chinook runs to the Soviet coast start in early May and continue to the end of August with no pronounced peak. The 1960 catch statistics of the Kamchatka Peninsula (Research Institute of Marine Fisheries and Oceanography of the U.S.S.R., 1961), show only 30 metric tons of chinook for West Kamchatka and 670 tons for East Kamchatka. The latter catches started in May and peaked in June with only one metric ton landed in August. Data are not available in sufficient detail to comment on the number of runs and races which may exist in the various Asian streams.

Life History in Fresh Water

The individual races found in various rivers and tributaries may have unique freshwater life histories and total life histories. While the literature establishes the existence of these differences, it does not broadly document them, nor describe them in detail.

It is apparent, for example, that the runs or races described by Fry (1961) spawn at different times. Some of the eggs, therefore, incubate in a falling temperature regime, while others incubate during rising temperatures. The time of hatching of eggs from these different races therefore differs, as well as the environmental and ecological conditions with which the resulting young must endure and cope. What effects, if any, the differences in season of emergence of fry from the gravel would have on later migration and distribution in marine waters are conjectural and substantially unknown.

Differences of the type found in the Sacramento River system are also found elsewhere. Mains and Smith (1955) reported on concurrent sampling for downstream migrants on (1) the Snake River, (2) the Columbia River above the mouth of the Snake and (3) the Yakima River, which joins the Columbia above the mouth of the Snake but below the Columbia River sampling point. The Snake and Columbia Rivers in this area are migation routes for both spring and fall migrating races of chinook adults. Table 2 illustrates some of the differences found in the resulting downstream migrants. (Hereinafter, the word "fingerlings" will apply to chinook lacking a freshwater annulus, while "yearlings" will include those that show one freshwater annulus.) These three areas show a dominant downstream migration in the spring, although a few chinook are found occasionally in other months in the Snake and Yakima Rivers. These data from Mains and Smith (1955) show differences in size, time and age of migration at three concurrent sampling locations on the Columbia River and its tributaries.

The reports of the U.S Army Corps of Engineers (i.e., 1950) show that chinook salmon fingerlings and yearlings are present every month of the year in the Bonneville Dam area. In the Taku River in Alaska, however, most chinook salmon migrate to sea in the April-June period, with the peak occurring in May (Meehan and Siniff, 1962). Smoker (1954) reported that fall run chinook salmon in Puget Sound normally migrate to salt water after about 90 days in fresh water while the spring run progeny may remain in fresh water for more than one year.

Rutter (1903) reported catching seaward migrants in the Sacramento River at Walnut Grove from January into May. His trap caught at least some downstream migrants daily with maximum numbers

Table 2. Results of concurrent sampling for downstream migrating chinook salmon at three locations in the Columbia River watershed (from Mains and Smith, 1955).

	Time of migration		Peak of migration		Age composition		Length in mm	
River	Fingerling	Yearling	Fingerling	Yearling	Fingerling (%)	Yearling (%)	Fingerling (range)	Yearling (modal)
Snake	March–April	April–June	April	June	7– 20	80–93	30–55	95–100
Columbia	March–April	June–July	April	June	76	24	20–55	85– 90
Yakima		April–August		May	100			125

occurring in March. While some yolk-sac fry were taken, sizes generally ranged from about 1½ inches (3.8 cm) at the start of the season to about three inches (7.6 cm) at the end. Gilbert (1913) reported that in Alaska as well as in the Sacramento River some chinook salmon pass to salt water in the spring and early summer while others remain in fresh water and go to sea as yearlings during their second spring. Hanson *et al.* (1940) found that a fall downstream migration occurred in some of the Sacramento River tributaries.

These examples have demonstrated that differences in growth and time of migration do occur among the juvenile chinook salmon from different races in a given river system and between races in different rivers. There are two additional features which may be characteristic of a watershed—(1) length of time in fresh water and (2) total age.

Age at Migration

Clark (1929) stated that 80 to 90 percent of the Sacramento chinook salmon have scales of the ocean nucleus type (as defined by Gilbert, 1913) and that chinook returned to the Sacramento primarily (50 percent) as four-year-olds. They also returned as five-year-olds, three-year-olds, six-year-olds and two-year-olds, in that descending order of abundance. Fry[2] reports that this age composition is no longer true; the four-year-olds predominate in some years, three-year-olds in some years; two-year-olds are common, five-year-olds less so, and six-year-olds quite scarce.

Rich (1920) seined at various places in the lower Columbia (excluding hatcheries) and found 97 chinook salmon which he classified as yearlings and 473 as fingerlings. Hence, about 80 percent of his samples had ocean type scales. He stated that his data suggested that the fastest growing individuals left for salt water first. It should be noted that Mains and Smith (1955) found yearling migrants into August and peak migrations in June, while Rich (1920) discontinued sampling after May 25. Rich (1920) also concluded that males and females migrated out of the Columbia River in equal numbers throughout the seasons of migration.

Rich and Holmes (1929) reported that spring chinook returned to the Columbia River in their third to sixth years, with the greatest number maturing in their fifth year; the six-year-olds exceeded the four-year-olds, with the three-year-olds being least common. For the fall chinook, the four-year-olds were apparently most abundant, with the five-year-olds second most abundant. Some two-year-old males and three-year-old females also occurred, but no six-year-olds were recorded. Van Hyning[3] reports that, at present, four- and five-year-olds are most abundant in the Columbia River spring chinook with very few six-year-olds; three- and four-year-olds are most abundant in the fall chinook.

Samples of Taku River seaward migrant chinook salmon were all of the stream type, with 94 percent being in their second year and six percent in their third year at time of migration, according to Meehan and Siniff (1962). However, Parker *et al.* (1954) presented contrary data from reading adult scales showing that most had ocean type scales. Although the matter is under study[4], it seems probable that the more recent work of Meehan and Siniff more accurately describes the true age composition, since it was done when scale reading methods were more advanced and on scales taken from small fish, not adults. Returning adults (Edson *et al.*, 1955) varied in age from two- to six-year-olds. Different levels of abundance for each yearclass of returning adults were indicated, depending on the sampling method—troll and gillnet catches being different from each other and both being different from catches of a fish wheel. In an estimated compilation by Edson *et al.* (1955), the five-year-olds were usually more abundant, followed by four-, three-, two- and six-year-olds, in that descending order.

In the Yukon River samples reported by Gilbert (1922), all were of the stream type. Two-year-old adults were absent and only one three-year-old was taken. All fish less than five years old were males. Six-year-olds of both sexes were more abundant than five-year-olds, seven-year-olds being the least common in the mixed-sex groups.

Throughout their North American range, then, chinook salmon may be expected to migrate to the sea over a rather wide range of time after hatching. At the southernmost point of their distribution, some may migrate as yolk-sac fry, although some may remain in fresh water for from a few months to a year. In the rivers farthest north, all may stay at least a

[2] Personal communication from D. H. Fry, Jr., to J. E. Mason, dated August 2, 1963.

[3] Personal communication from Jack M. Van Hyning to J. E. Mason, dated Nov. 26, 1963.

[4] Personal communication from Dr. William R. Meehan, Alaska Department of Fish and Game, to J. E. Mason, dated February 14, 1963.

year in fresh water. The age at maturity varied from one to six years in more southern areas, with four- and five-year-olds being more abundant. Farther to the north, the five- and six-year-olds were more abundant.

Migrations in Coastal Waters

The preceding material has established that most downstream migrants enter salt water in the spring, as fingerlings and yearlings, at least in streams south of Alaska. Rich (1920) noted a tendency for the larger downstream migrants of a particular tributary to migrate earlier than the smaller. Rich and Holmes (1929) presented data to show that there were many gradations between typical stream and ocean types of scales, which are apparently related to the time and method of entry into brackish water and the duration of stay therein. Clark (1929) reached the same conclusions for the Sacramento River chinook salmon and Snyder (1922 and 1923) showed that departures from the typical scale types also occurred in Klamath River fish.

In the brackish and marine environment, almost nothing is known of growth, distribution and migration until the fish are of sufficient size to be taken in commercial troll or sport fisheries. Pressey (1953) shows that the size of first entry into the sport fishery of Puget Sound is at about 11 inches (27.9 cm) and about 15 inches (38.1 cm) in the Strait of Juan de Fuca area. Fraser (1917) reported immatures from the Departure Bay area of British Columbia a little in excess of 10 inches (25.4 cm) long. The Columbia River troll fishery takes chinook as small as 17 to 18 inches (43.2 to 45.7 cm) in length (Van Hyning, 1951), although smaller chinook are caught but not landed. Neave (1951) reported on tagging in the troll fishery of the west coast of Vancouver Island. The age composition included chinook of the 2_1 age group and individuals below 24.5 inches (62.2 cm) in length and less than five pounds (2.3 kg) in weight. Immature chinook salmon were thus included, although the minimum size caught is not a matter of record.

All the Puget Sound-British Columbia and Columbia River samples were obtained from areas where chinook salmon populations from more than one river may be found. The only available data on the origin of these mixed populations is from marking experiments, as follows. The most northerly recoveries recorded by Rich and Holmes (1929), reporting on results of liberating marked chinook salmon at Columbia River hatcheries, were one spring run chinook from Dixon Entrance, southeastern Alaska, and two fall run chinook, one each from near Barkley Sound and near Ucluelet (west coast of Vancouver Island). The Cowichan River chinook marked in the years 1937 to 1944 resulted in over 65 recoveries in the Georgia Strait area and along the west coast of Vancouver Island (Neave, 1941a, 1941b, 1949; Neave and Pritchard, 1942).

More recent Columbia River marking experiments, as reported in Pacific Marine Fisheries Commission (1959), have resulted in recoveries in Washington, Oregon, British Columbia and in southeastern Alaskan commercial fisheries. These experiments were not specifically designed for studies of ocean distribution and do not materially aid in the understanding of this distribution.

Distribution Indicated by Tagging in Southeastern Alaska

On the basis of scale type, age composition and growth, Parker and Kirkness (1951) indicated that southeastern Alaskan chinook salmon are of two types, those found in inside waters and those found in outside coastal waters. Parker and Kirkness (1956) divided the latter into three groups by the characteristics of the chinook salmon found there. Those in the Cross Sound to Cape Fairweather area averaged about 27.5 inches (69.9 cm) in fork length. Most (probably in excess of 80 percent) were immature, with 4_1's being most abundant, followed by 3_1's. Chinook salmon found on the west coast of Chichagof Island were mostly (probably in excess of 80 percent) mature. Their modal fork length was between 30.0 inches (76.2 cm) and 32.5 inches (82.6 cm). Age group 4_1 was most abundant, followed by 5_1.

Since most recoveries (86.5 percent) of tags applied in outside waters were made outside of Alaska, Parker and Kirkness (1951, 1956) were of the opinion that the chinook salmon in outside waters were primarily from streams to the south of Alaska. Chinook salmon on the west coast of Prince of Wales Island were the largest of the three areas, with the principal modal fork length lying between 35.0 inches (88.9 cm) and 37.5 inches (95.3 cm). Again, probably in excess of 80 percent were mature, with the dominant age groups being 4_1 and 5_1, in that order. Rich and Ball (1933) reported that about 60 percent of the tags recovered from tagging off Baranof Island in 1926 and 1927 came from the Columbia River. Thus, two tagging experiments separated by many years resulted in substantial numbers of recoveries in fisheries to the south. In inside passage areas, all adult chinook tagged were of the ocean scale type as compared to 10-20 percent in outside waters. The 1951 tagging reported by Parker *et al.* (1952) resulted in no rec-

overies from tags applied north of Cross Sound, while those recovered from tagging south of Cross Sound supported the opinion of Parker and Kirkness (1951)—that chinook salmon in that area were primarily from streams to the south of Alaska.

The spring season tagging in inside passage waters such as Stephens Passage and Clarence Strait resulted in substantial numbers being recovered in Alaskan rivers when tagging was in close proximity to the rivers. When tagging was removed from such rivers or carried out later in the season, numbers were recovered in areas to the south and in British Columbia with only rare recoveries to the north and west of the tagging locations.

Kirkness *et al.* (1953) reported on tagging chinook salmon north of Cape Spencer in 1952. The returns followed the pattern for previous tagging in the area and also resulted in the first returns in an Alaskan river (the Taku) from Alaskan tagging. They concluded that the stocks of chinook salmon north of Cape Spencer were composed largely of immatures and that their origins were primarily from rivers to the south. Tagging in southeastern Alaska in 1951 and 1952 resulted in northern British Columbia recoveries, but none from the Fraser or Columbia Rivers.

Distribution Indicated by Tagging in British Columbia

Milne (1957) summarized chinook salmon tagging in British Columbia in the years 1925–1930 and compared the results to tagging in 1949–1952. He reported very little difference in total percentage of tags recovered between the two time periods. In both periods, the majority of the chinook salmon tagged in outside coastal waters travelled in a southeasterly direction toward the Fraser and Columbia Rivers. In recent years, more were recovered in British Columbia waters than in earlier years. He states that " Off the southwestern part of Vancouver Island many small immature fish are also captured while they are foraging in the ocean a year or two prior to the spawning migration."

Distribution Indicated by Tagging in Washington

Kauffman (1951) reported on tagging of chinook salmon in 1948 and 1949 at Swiftsure Bank and at Umatilla, recoveries from tagging in other areas being too few for conclusions. The Swiftsure tagging resulted in a rather high rate of recovery (55-62 percent of those recovered) in the general tagging area, and a substantial number of recoveries (26 out of a total of 58 recoveries from 1949 tagging) one or more years after tagging. A high abundance of immatures in the tagging area was thus indicated. Recoveries also came from areas northwest of the tagging site to near the northern tip of Vancouver Island and from the Fraser and Columbia Rivers. The Umatilla tagging showed a movement of chinook to the Sacramento and Columbia River areas, Puget Sound and along the coast of Vancouver Island.

Distribution Indicated by Tagging in Oregon

Van Hyning (1951) reported on tagging undersized chinook (less than the legal 27 inches, 68.6 cm) in 1948 and both undersized and larger chinook in 1949 on the coast of Oregon. Very few tags were applied at the three sites, the Columbia River, Newport and Coos Bay. Only five tags were recovered from the Columbia River tagging, none from Newport and six from Coos Bay. The recoveries indicated a northward movement from the Columbia River along the coast of Washington to the coast of British Columbia. Two of the five tags applied near the Columbia were recovered in the Columbia River and one in San Francisco Bay. Some of the tags from the Coos Bay tagging were recovered north and one was recovered south of the tagging location. In scale samples from Astoria and Newport taken in 1947, Van Hyning found that about 72 percent were of the ocean nucleus type compared to about 78 percent reported by Rich (1920) for this general area.

Distribution Indicated by Tagging in California

Fry and Hughes (1951) reported on California tagging of chinook in the years 1939 to 1942 and 1948 to 1949. The results showed that the Sacramento-San Joaquin River systems were the primary suppliers of chinook salmon to the California coastal troll fishery, although a few recoveries came from California streams north of the Sacramento. Point Arena seemed to be a dividing point. Most of those tagged south of this point were recovered to the south, while most of those tagged to the north were recovered to the north.

Summary of Tagging

These various tagging experiments indicate that most chinook salmon yearling and fingerling migrants must move to the northward on entering marine waters. For the Columbia River chinook, this migration is most pronounced. However, a few chinook from many areas may travel to the south. Evidence from tagging has demonstrated that large numbers of chinook from the Columbia River and southern British Columbia river systems migrate into

the troll fishery areas of British Columbia and Alaska. Along the inside shores of southeastern Alaska, British Columbia and Puget Sound, there are apparently chinook salmon which do not migrate to any great extent in a northward direction. Present evidence indicates that some of the chinook in inside waters may not intermingle to any great extent with those of the outside coastal areas of Washington, British Columbia and some Alaskan waters.

CHINOOK SALMON STOCKS IN NORTH AMERICA AND ASIA

The numbers of chinook salmon caught in North America for the years 1920 through 1961 are summarized in Table 3. Similar statistics for Asia for the years 1909 through 1961 are presented in Table 4. These commercial fisheries data have generally been more complete and accurate in more recent years. While California, for example, adopted its basic " fish ticket " or multiple sales slip system in 1918, for many years all species of salmon were combined so that single species data are unavailable for the years 1920 through 1946. Oregon adopted a fish ticket system in 1923, and adoption of and improvements in this system followed in Washington in 1935 and in both British Columbia and Alaska in 1951.

Soviet and Japanese commercial catch statistics were unavailable for some years, even into the 1930's (Table 4). In general, however, the data were more detailed since World War II, and were later improved by the release of Japanese mothership data for $2° \times 5°$ statistical areas and ten-day periods. Tables 3 and 4 both show omissions in knowledge of commercial catch statistics. The figures which most accurately represent the catches of both continents are probably those following the close of World War II.

While the accuracy and detail of North American, Japanese and Soviet commercial catch data increased in recent years, a similar improvement in the recording of North American sport fisheries and other personal use catches was not apparent. The sport fisheries in ocean waters have grown tremendously in post World War II years and fishing effort in inshore and freshwater areas has also increased. However, none of the fishery agencies has developed a means of completely censusing the numbers of chinook landed in diverse fishing areas over protracted seasons by various types of non-commercial fishing gear. As a result, the sport catches shown in Table 3 are believed to be minimum figures in most cases.

In spite of these deficiencies, when the total chinook landings of the two continents are compared, North American catches greatly exceed the combined catches by the U.S.S.R. and Japan (Figure 4). It is also apparent that in spite of substantial fluctuations in the North American catches since World War II, there has been an increasing trend in numbers of chinook caught. The combined Soviet and Japanese catches since 1952 have shown a general increase which is probably attributable to expansion of both the Soviet coastal and Japanese mothership fisheries. Figure 4 shows that since World War II the North American catch has tended to increase. Figure 5 shows that in this period the United States catches have tended to fall, while those for Canada have tended to rise. It should be noted that the sport catches are missing for some states for 1959, 1960 and 1961, which could influence the trends of the catches. However, the trends remain the same if Figure 5 is replotted with sport catches assumed to be the highest of record in each state for the missing years.

In recent years, the Japanese commercial catch has been taken primarily in offshore waters by gillnets and to some extent longlines. In coastal waters of both Japan and the U.S.S.R., both traps and nets are used. The North American catch is primarily taken by trollers operating in both open coastal and inside waters. A major exception is commercial fishing in Bristol Bay and its tributaries, which is exclusively by gillnet. In inside waters, gillnets take substantial numbers, particularly in river estuaries such as those of the Columbia and Fraser Rivers and places such as Cook Inlet in Alaska. In some areas, traps, dip nets and fish wheels still operate, most commonly for personal use fisheries.

The troll fisheries make appreciable catches starting in May, with catches substantially reduced after August. To illustrate the seasonal variation in catch between different North American areas, the percentiles of representative troll catches for the year 1960 were calculated (Table 5). It should be noted that these data were subject to the effects of variations in regulations, fishing effort, weather and market conditions.

DISTRIBUTION AND ABUNDANCE OF CHINOOK SALMON IN OFFSHORE WATERS

The offshore distribution and abundance of chinook salmon will be described from catches of research vessels using purse seines, gillnets and longlines, and from catches of the Japanese mothership fishery. The data to be used for these purposes were taken from

TABLE 3. North American catches of chinook salmon, in thousands of fish, with available data on sport catches given in parentheses.

Year	Alaska[1]	British Columbia[2]	Washington[3]	Oregon[4]	California[5]	Total
1920	775.5	641.8	771.4	—		2,188.7
1921	826.4	406.8	598.7	—		1,831.9
1922	770.3	373.2	562.9	843.3		2,549.7
1923	681.4	343.0	678.2	1,157.4		2,860.0
1924	794.3	305.8	1,267.5	1,307.0		3,674.6
1925	816.6	666.5	1,219.2	1,428.0		4,130.3
1926	588.6	489.9	980.7	1,093.2		3,152.4
1927	967.3	614.3	1,090.0	1,142.1		3,813.7
1928	656.6	415.0	894.7	800.3		2,766.6
1929	768.1	344.8	972.9	729.6		2,815.4
1930	892.9	539.4	1,025.1	791.0		3,248.4
1931	680.3	424.7	1,042.6	926.5		3,074.1
1932	882.3	645.6	910.2	710.6		3,148.7
1933	608.7	448.2	894.0	874.9		2,825.8
1934	559.7	1,737.3	872.5	807.3		3,976.8
1935	800.5	1,341.4	563.1	821.0		3,526.0
1936	894.1	1,634.4	610.3	968.1		4,106.9
1937	1,071.8	813.8	652.4	1,070.5		3,608.5
1938	927.7	330.7	434.7(27.5)	735.9		2,456.5
1939	817.6	361.0	468.5(34.8)	754.0		2,435.9
1940	574.2	326.3	588.1(34.1)	807.6		2,330.3
1941	1,126.2	713.3	656.8(29.8)	1,026.6		3,552.7
1942	739.8	415.7	607.7(8.3)	940.2		2,711.7
1943	629.6	1,076.4	487.0	623.2		2,816.2
1944	506.2	276.4	497.2	751.5		2,031.3
1945	608.2	502.1	546.1	779.2		2,435.6
1946	739.9	780.5	643.4(23.4)	866.3		3,053.5
1947	717.8	874.3	637.2(12.8)	1,004.6	759(5)	4,010.7
1948	677.9	513.9	572.8(12.0)	927.4	517(11)	3,232.0
1949	703.8	*	507.8(105.2)	632.9(8.0)	438(23)	2,418.7**
1950	609.9	*	480.4(114.6)	567.9(11.0)	487(57)	2,327.8**
1951	789.5	794.0	594.8(139.2)	620.7(10.0)	476(103)	3,527.2
1952	735.3	905.4	662.1(213.0)	519.0(11.0)	512(123)	3,680.8
1953	713.0	1,013.9(75)	630.4(152.2)	445.0(15.0)	533(141)	3,718.5
1954	610.4	876.8(76)	570.1(219.1)	428.7(17.0)	828(171)	3,797.1
1955	582.1	872.0(90)	651.2(228.9)	627.7(59.0)	868(184)	4,162.9
1956	458.0	983.1(106)	519.3(318.6)	677.8(51.0)	1,026(163)	4,302.8
1957	513.8	938.1(135)	586.2(331.9)	461.5(79.0)	491(64)	3,600.5
1958	550.2	1,068.7(144)	481.6(235.1)	398.8(74.0)	375(65)	3,392.4
1959	601.2	948.3(117)	375.0(197.0)	247.2	514	2,999.7
1960	547.2	742.5(93)	288.3(195.2)	338.3	540	2,744.5
1961	503.6	685.3(67)	371.1(205.6)	297.5	792	2,922.1

* No data available in number of fish for B.C. catches in 1949 and 1950.

** Incomplete total.

[1] From Kasahara (1963), Table 47.

[2] From Kasahara (1963), Table 60 (commercial) and Table 80 (sport). Sport catches include 25% of "grilse" catches as given by Kasahara.

[3] From 1920 to 1934, from Kasahara (1963), using 19.48 lbs per fish. From 1935 to 1961, from 1962 Annual Report, Washington State Department of Fisheries, except that sport catches given for 1938 to 1942 are from Annual Bulletins 38, 39, 40, 41 and 42 of the Washington State Department of Fisheries.

[4] For 1922 to 1955, Oregon commercial catches in Table 69 of Kasahara (1963) were converted from metric tons to pounds (2,204.59 lbs per metric ton) and then to number of fish (15 lbs per fish; see Kasahara's note 7, Table 75); for 1956 to 1961, data were taken from INPFC Statistical Yearbooks. Sport catches from 1949 to 1958 are from Kasahara (1963), Table 82.

[5] For the years prior 1947, there are no data available on catches of chinook salmon, since catches of coho and chinook were not separated. Commercial catches shown here are from D. H. Fry, Jr., California Department of Fish and Game, as given in a letter to J. E. Mas[illegible] dated August 2, 1963. Sport catches for 1947 to 1958 are from Kasahara (1963), Table 82.

TABLE 4. Commercial catch of chinook salmon, in thousands of fish, by Japanese and U.S.S.R. fisheries.

Year	Catch by Japan from U.S.S.R. coast[1]	U.S.S.R. coastal catch[2]	Japanese mothership and North Kuril fisheries[3]	Total
1909		2.6		2.6
1910		0.4		0.4
1911	6.0	8.2		14.2
1912	5.1	25.4		30.5
1913	28.2	7.3		35.5
1914	11.8	8.7		20.5
1915	17.6	10.1		27.7
1916	15.0	8.8		23.8
1917	14.9	24.4		39.3
1918	12.0	79.4		91.4
1919	50.6	0.8		51.4
1920	70.3	6.5		76.8
1921	64.6			64.6**
1922	35.8	39.0		74.8
1923	24.8			24.8**
1924	23.7			23.7**
1925	39.6			39.6**
1926	77.0			77.0**
1927	98.2	7.8		106.0
1928	68.6	18.4		87.0
1929	82.5	26.5		109.0
1930	111.6	67.4	3.3	182.3
1931	74.8	40.2	4.7	119.7
1932	74.8	53.2	2.8	130.8
1933	35.5	15.5	1.1	52.1
1934	68.7	23.3	3.2	95.2
1935	103.2	40.8	20.3	164.3
1936	77.0	65.0	41.4	183.4
1937	123.4		32.6	156.0**
1938	91.4		28.8	120.2**
1939	57.6		9.1	66.7**
1940	67.3	22.0	12.0	101.3
1941	66.3	57.0	13.4	136.7
1942	31.4	36.0	16.0	73.4
1943	*	48.0	4.5	52.8
1944	*	17.0	*	17.2
1945		38.0	*	38.0
1946		81.0		81.0
1947		81.0		81.0
1948		130.0		130.0
1949		75.0		75.0
1950		62.0		62.0
1951		72.0		72.0
1952		66.0	1.0	67.0
1953		88.0	8.0	96.0
1954		65.0	74.0	139.0
1955		134.0	76.0	210.0
1956		110.0	137.0	247.0
1957		90.0	31.0	121.0
1958		70.0	46.0	116.0
1959		98.3	68.0	166.3
1960		70.0	180.0	250.0
1961		65.0	31.0	96.0

TABLE 4. (Continued)

* Less than 500 fish.

** Incomplete total.

[1] From Kasahara (1963), Table 15.

[2] For 1909 and 1910, from Baievsky (1926). For 1911 to 1922, by subtraction of Kasahara's Japanese catch from total U.S.S.R. coastal catches given by Baievsky (1926); for 1927 to 1936, by subtraction of Japanese catch from total U.S.S.R. coastal catch, both as given in Kasahara (1963); for 1940 to 1961, from metric ton figures given by Kasahara (1963) in Table 29, converted to number of fish using a conversion factor of 22 lbs per fish approximated from 1958 through 1961 averages given in Table 32 of Kasahara (1963).

[3] For 1930 to 1945, from Kasahara (1963), Tables 34 and 35; for 1952 to 1961, from Kasahara's Table 37 (mothership catches only).

the annual reports of the International North Pacific Fisheries Commission (1955–1961), INPFC Statistical Yearbooks for 1952 through 1961, Neave *et al.* (1962), French (1964), Powell and Peterson (1957) and Fisheries Agency of Japan (1962). Before proceeding, some of the limitations and possible sources of error in the data should be recognized.

Limitations of the Data

The research vessels of Canada, Japan and the United States have used a variety of gear in the period 1955 through 1962, including troll lines, purse seines, longlines and gillnets. Data from trolling were too few to be of any help in describing distribution and abundance, but appreciable numbers of chinook salmon have been taken in purse seines. However, since purse seines were usually operated in the more coastal waters and principally for the purpose of obtaining salmon for tagging, the resulting data are of limited use in describing offshore distribution of chinook. The same criticism can be made of some of the longline experimental fishing, although Canadian and Japanese longline fishing in 1962 was carried out in a manner which adds to knowledge of distribution and abundance.

The most consistent data are those procured from the use of gillnets fished in surface waters. Those fished

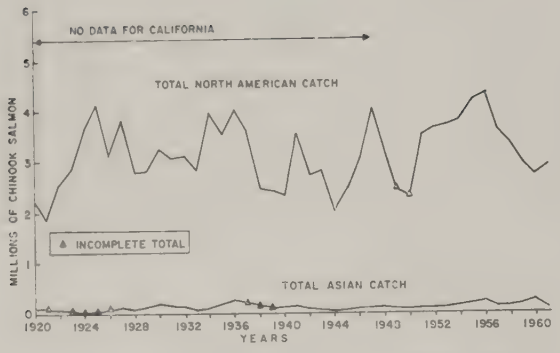

FIGURE 4. Chinook salmon catches (in millions of fish) from North America and Asia (U.S.S.R. and Japan), 1920-1960. Data from Tables 3 and 4.

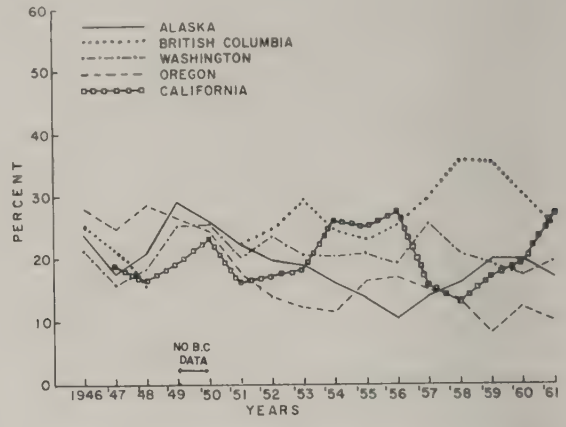

FIGURE 5. Chinook salmon catches in North America, by area, as percentages of total North American catch. Data from Table 3.

TABLE 5. Percentiles of chinook salmon troll catches by areas in 1960[1].

Area	10%	25%	50%	75%	90%
Alaska					
Icy Strait and Western	May 21	June 4	June 18	July 16	Aug. 20
British Columbia					
Areas 1 and 2	May 28	June 18	July 9	July 23	July 30
Areas 22-27 and C	May 14	June 11	July 30	Aug. 13	Sept. 10
Columbia River					
Oregon Coastal	May 28	July 2	Aug. 6	Aug. 20	Sept. 17
California					
San Francisco	Early May	Early June	June	July	Mid-August

[1] Data taken from INPFC Statistical Yearbook for 1960.

at depths in studies of vertical distribution, again, are of no material value in describing offshore distribution and have been omitted. The gillnets were typically of the INPFC standard meshes, that is, 5¼", 4½", 3¼", and 2½" stretched mesh (13.3, 11.4, 8.3, 6.4 cm), although many other mesh sizes and both monofilament and multifilament synthetic web materials have been used, all in various amounts and in various combinations.

Since gillnets were used by all three nations for extended periods of time over broad ocean areas, it would appear desirable to describe distribution and abundance in terms of catch per unit of effort. Examination of the data revealed that the combined chinook catches by research vessels of Canada, Japan and the United States in the years 1955 through 1962 totalled less than 2,000 chinook for both surface fishing gillnets and the longline data which could be used to describe offshore distribution. The number of chinook salmon caught was almost insignificant in terms of catch in numbers and in catch per unit of gear. The maximum figures given by Manzer *et al.* (MS 1963) for the Japanese landbased fishery by 10-day periods in the years 1956 through 1960 are 1.17, 0.22 and 0.16 chinook per tan (about 180 feet). All other catches amounted to only a few hundredths of a chinook per tan. In the Japanese mothership fishery, the maximum recorded catches per tan by months and areas were 0.23 and 0.09 chinook per tan, with most figures falling below 0.03 chinook per tan (INPFC Statistical Yearbooks 1954 through 1960). If the data for research vessels, the landbased fishery, or the mothership fishery were to be further divided to express catch per unit by mesh size, they would have even less significance. Since the total number of chinook caught was so small and since such a variety of gillnets was used, it was decided to avoid expressing results in terms of catch per unit of fishing gear. The data are expressed in terms of fishing position, numbers of occasions fishing was

carried out at that position and the number of chinook caught. This approximates catch per unit in terms of catch per set.

The approximate total of 2,000 chinook caught over eight years of fishing is a number of such small magnitude that it makes it impossible to compare abundance on a monthly basis or to compare catches by years. As a result, the seasonal changes discussed below for research vessel catches are based on combined data by months for 1955 through 1962. This totally obscures differences in abundance by years or seasonal variation which may be related to differences in ocean environment.

While research vessel fishing is intended to give unbiased estimates of salmon populations at each fishing location, the sampling gear is known to be selective. These vessels have usually fished surface waters and while the gillnet mesh sizes have generally ranged from $2\frac{1}{2}$ to $5\frac{1}{4}$ inches (6.4 to 13.3 cm), the most efficient sizes for retaining larger and smaller chinook were not used. The bias due to this factor cannot be evaluated. Biases are also introduced from the use of longline gear, hook sizes and bait type both being recognized as introducing size and species selection. Here again the degree of bias is unknown.

The species identification of catches by research vessels are subject to correction after laboratory examination of specimens, such correction occurring on some occasions after the annual reports of the International North Pacific Fisheries Commission had been published. While there are occasions of misidentification of species or errors in recording data, they are relatively few, and this type of error should not significantly affect the analyses to follow.

Another factor limiting the analyses is the relative lack of any numbers of chinook, not only in research vessel catches as was pointed out, but in the mothership fisheries, as shown in Table 6 for operations in 1957, which year was selected at random for demonstration purposes. The number of chinook is virtually insignificant in terms of catch in numbers and catch per unit of gear as compared to other species.

Other sources of bias in the commercial fishing data are selective fishing by area, by gear and by time for other species which may be more abundant or otherwise preferred. Therefore, catch, or catch per unit of effort, data of commercial gear cannot be used as unbiased indices of the distribution and abundance of chinook salmon. Unfortunately, it is not possible to estimate the degree of bias introduced by selective fishing.

There are other sources of error which may act in combination with the above. Table 7 compares catches by Japanese research vessels and motherships for specific times and areas. The table includes sockeye, chum, pink and coho salmon for illustration purposes, since so few chinook were taken. It can be seen that in 1957 the catches per tan by species for two research vessels were of the same general order of magnitude. However, the catch per tan of the 1957 mothership fishery was higher than that of the research vessels for some species (sockeye and pink) and lower for others (chum and coho). In 1958 and 1959, the mothership catches per tan were usually higher than those of the research vessels for all species (approximately two to four times). In 1960, however, mothership catches were lower than research vessel catches for all species except sockeye. These variations may be partly explained on the basis of (1) grossly dissimilar amounts of effort by the two fisheries, (2) the few occasions when both fisheries were operated concur-

Table 6. Catch and catch per unit of effort in 1957 for salmon caught in gillnets by Japanese and Canadian research vessels and the Japanese mothership fishery[1].

Operation	Species				
	Sockeye	Chum	Pink	Coho	Chinook
Japanese research vessels (2,203 tans)					
Number of fish	4,297	3,004	5,516	516	7
Mean catch per tan	1.9	1.4	2.5	0.2	0.003
Canadian research vessels (2,096 shackles)					
Number of fish	998	1,797	519	355	5
Mean catch per shackle	0.5	0.9	0.2	0.2	0.002
Japanese motherships (6,619,089 tans)					
Number of fish	19,822,540	9,246,132	21,045,585	339,623	31,104
Mean catch per tan	3.0	1.4	0.32	0.05	0.005

[1] Data from INPFC Annual Report 1957.

TABLE 7. Catch and catch per unit of effort by species of salmon for Japanese research and mothership vessels using the same types of gear in the same areas in the same time periods in the years 1957 through 1960[1].

Year	Vessel	Date	Area[2]	Sockeye	Chum	Pink	Coho	Chinook	Tans
1957	*Kano-maru*	July 19–30	E6050, E6052	450	665	272	57	2	274
			Catch per tan	1.6	2.43	1.06	0.21	0.007	
1957	*Etsuzan-maru*	July 15–30	E6050, E6052	570	542	733	229	1	392
			Catch per tan	1.45	1.38	1.87	0.58	0.003	
		July 19–30	E6050, E6052	374	427	417	227	—	280
			Catch per tan	1.34	1.53	1.49	0.81		
1957	Mothership	July	E6050, E6052	2,301,830	665,063	5,382,496	111,628	4,766	959,152
			Catch per tan	2.4	0.69	5.6	0.12	0.005	
1958	*Kano-maru*	June 1–30	E6052, E6054	98	90	13	—	—	144
			Catch per tan	0.68	0.62	0.09			
1958	Mothership	June	E6052, E6054	224,811	262,557	234,710	68	1,423	182,879
			Catch per tan	1.23	1.44	1.28	0.0003	0.008	
1959	*Wakashio-maru*	June 10–20	E6048, E6052	215	230	193	1	—	260
			Catch per tan	0.83	0.89	0.74	0.004		
1959	Mothership	June	E6048, E6052	345,255	985,062	1,179,532	1,171	725	378,600
			Catch per tan	0.91	2.6	3.1	0.003	0.002	
1960	*Etsuzan-maru*	Aug. 10	E6552	55	36	1	34	—	60
			Catch per tan	0.92	0.6	0.02	0.57		
1960	Mothership	Aug. 1–10	E6552	26,703	2,036	41	171	—	8,448
			Catch per tan	3.16	0.24	0.005	0.02		

[1] Data from INPFC Annual Reports, 1957, 1958, 1959 and 1960.
[2] See Figure 6.

rently, (3) commercial fishery statistics (except 1960) being tabulated by months whereas the research vessel catches were by specific days, and (4) the fact that the mothership fishing areas had boundaries as large as two degrees of latitude and five degrees of longitude. These various possible sources of error for sockeye, chum and pink salmon are assumed to apply as well to chinook salmon.

It is thus apparent that neither the research vessel nor mothership data for chinook salmon can be accepted as being superior. In most cases, the differences in data from the two sources may be viewed as being due, perhaps, more to sampling differences than to biological phenomena. As a result, trends or conclusions can be indicated only very generally.

The following material concerning distribution and abundance is based on chinook salmon catches in surface waters. If these fish occur in surface waters only occasionally or only seasonally, then the actual distribution of most of the chinook may be grossly different from any conclusions reached here.

DISTRIBUTION AND ABUNDANCE DESCRIBED FROM RESEARCH VESSELS USING PURSE SEINES

The purse seine catch data given by Hartt (1962) are summarized in Table 8 by INPFC statistical area (Figure 6), month, catch per set, number of sets and for sets open to the east and west. While Hartt did not give specific information on maturity, he stated the opinion that most of the chinook salmon caught were immature, hence the following material is thought to apply primarily to immature chinook. The totals in Table 8 show a slightly higher average catch per set for sets open to the east than to the west, suggesting a possible westerly migration. A change in abundance in relation to time is also suggested for sets open to the east, as well as a substantial increase in abundance after the month of May. Such changes are not apparent in sets open to the west, due, at least in part, to the small number of sets and small catches of chinook in May, July and August.

Data for the areas in which chinook were caught in three or more consecutive months are summarized in greater detail in Table 9. Only areas E7052, E7550, 8050 and W7052, involving sets open to the east, met the three month criterion. While areas E7052 and E7550 in Table 8 show an increasing abundance of chinook in succeeding months, Table 9 shows that the changes were the result of combining data and were not actually time related. In Table 8, area W7052 shows an increased abundance in July as compared to June, but in Table 9 it is apparent only for 1957 and includes a total of only nine sets. The 1958 data

TABLE 8. Chinook catch per purse seine set for the combined years 1956 through 1958. Numbers in parentheses are total numbers of sets[1].

Area code number	Open to East					Open to West				
	May	June	July	Aug.	Sept.	May	June	July	Aug.	Sept.
E6554			0 (1)							
E7050	0.3 (3)	0 (1)	0.8 (14)			0 (0)		0.5 (2)		
E7052	0 (3)	0.07 (14)	0.3 (35)	0.5 (21)		0 (2)	0 (24)	0 (1)	0 (4)	
E7054		1.3 (3)	0 (2)			0 (1)	0.7 (3)	0 (1)		
E7548			0.5 (2)					0 (1)		
E7550	0 (1)	0.6 (5)	0.25 (4)	0.45 (13)			0 (3)	0 (3)	0 (6)	
E7552	0 (1)	0 (1)	1 (1)	0 (2)		2.5 (2)	0 (1)	0 (1)	1 (1)	
E7554			0 (1)					0 (1)		
8048			2 (1)					0 (1)		
8050	0 (2)	0.17 (23)	1 (60)	0.70 (44)		0 (4)	0 (1)	0 (3)	0 (1)	
8052	0 (1)	0 (1)	0.17 (6)			0.2 (5)	1 (3)	0 (2)		
8054		2 (2)	1 (1)				2.7 (3)	0 (1)		
8056		1 (1)					0 (1)			
W7550	0 (1)	0 (3)	0.6 (5)	2.3 (3)			0 (3)	0 (1)		
W7552		0.3 (1)	0 (2)				0 (1)			
W7556		4 (2)					0.3 (10)			
W7558							0 (1)			
W7560							0 (1)			
W7052		0.2 (35)	12 (8)	1.5 (4)			0.3 (6)	0.5 (4)		
W7054		0.25 (4)					0.4 (10)			
W7056							0.14 (14)			
W6552	0 (6)					0.3 (3)				
W6554		0.07 (15)	0 (2)							
W6050				0 (1)					0 (1)	
W6052				0 (4)						
W6054			0 (2)	1 (7)	1.5 (2)			0 (1)	2 (2)	
W5554		0 (6)		1.5 (8)	0 (2)		0 (1)	0 (2)	0 (1)	

Continued

TABLE 8. (Continued)

Area code number	Open to East					Open to West				
	May	June	July	Aug.	Sept.	May	June	July	Aug.	Sept.
W5556				0.2 (5)	1 (2)				5 (1)	
W5558										4 (1)
W5054		0 (1)								
W5056				0 (1)	0 (3)					0.5 (2)
W4554						0 (1)				
W4556					0 (1)					0 (3)
W4054										0 (1)
W4056					2 (2)					4.3 (3)
W4058										0 (1)
W3554					0 (2)					0 (2)
W3048										2.2 (13)
W3050					2.3 (3)					
Total chinook caught	1	37	188	80	16	7	24	3	10	46
Total sets	18	118	147	113	17	18	86	25	17	26
Catch per set	0.05	0.31	1.28	0.71	0.94	0.39	0.28	0.12	0.59	1.8
	Total chinook caught: 322					Total chinook caught: 90				
	Total sets: 413					Total sets: 172				
	Catch per set: 0.77					Catch per set: 0.52				

[1] Data from Hartt (1962).

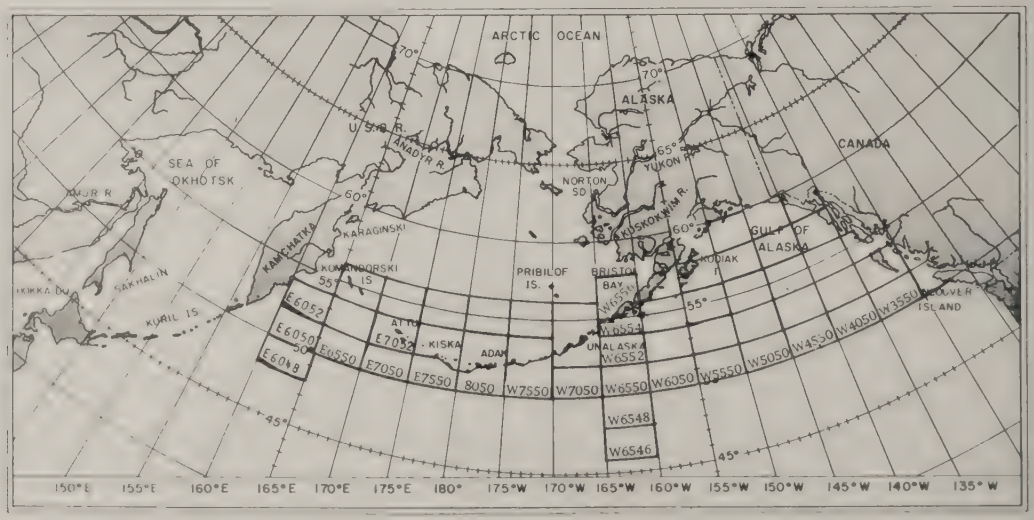

FIGURE 6. Reference map with key to area coding.

Table 9. Chinook catch per purse seine set for sets open to the east. Numbers in parentheses are numbers of sets[1].

Year and area		May	June	July	August
1956	E7052	(0)	(0)	(0)	(0)
	E7550	(0)	(0)	(0)	(0)
	8050	(0)	0.11 (9)	0.06(17)	0.78(18)
	W7052	(0)	0.19(31)	(0)	5.0 (1)
1957	E7052	(0)	0 (4)	0.06(17)	0.65(17)
	E7550	(0)	1.00 (3)	0.25 (4)	0.50(12)
	8050	0(1)	0.20 (5)	1.55(29)	0.69(13)
	W7052	(0)	0.25 (4)	1.60 (5)	0 (1)
1958	E7052	0(3)	0.10(10)	0.56(18)	0 (4)
	E7550	0(1)	0 (2)	(0)	0 (1)
	8050	(0)	0.22 (9)	1.00(14)	0.62(13)
	W7052	(0)	(0)	29.33 (3)	0.5 (2)

[1] Data from Hartt (1962).

were unusual in that the three sets made on July 2, 3 and 4 resulted in individual catches of 47, 27 and 14 chinook salmon on successive days. In Table 8, area 8050 shows increases in abundance of chinook in June and July, with a decline in August. Table 9 shows this same trend for area 8050 in 1957 and 1958; however, in 1956, the catch per set was lowest in July and highest in August.

The suggested westerly migration of chinook salmon indicates a possibility that they would become more abundant in the more western areas later in the season. This seems apparent in Table 9 for the 1957 data, which are more extensive than for 1956 or 1958.

The generally higher catches per purse seine set for sets open to the east as compared to the west suggest a westerly movement of chinook in areas W7550, 8050, E7550 and E7052, adjacent to and south of the Aleutian Islands. While a total of only five sets was made in May in these four areas in 1956 through 1958, the data indicate that chinook were more abundant in June than in May. Catches in area 8050 for 1957 and 1958 indicate peak abundance in July and a decline in August, changes not clearly apparent in 1956 or in other areas. The 1957 data suggest that chinook become more abundant in the more western areas in August, possibly as a result of a migration to the west suggested by the differences between catches of purse seines set open to the east and open to the west. The successive catches of 47, 27 and 14 chinook per set in area W7052 in 1958 show that chinook may be found in concentrations in some areas and times.

Distribution and Abundance Described from Research Vessels Using Gillnets

Figures 7 through 13 show summaries by months of positions and catches of chinook salmon by research vessels using surface fishing gillnets in the years 1955 through 1962. Each open circle shows a set location with no chinook catch. If more than one set was made, the number is shown in the upper part of or at the left of each circle. If one or more chinook was caught, the number is given below or to the right in each circle.

In offshore Pacific Ocean waters, the Okhotsk Sea and the Bering Sea, chinook were taken over nineteen degrees of latitude, from 41°N latitude (Figure 7) to 60°N (Figures 8 and 10) and across the entire Pacific from North America into the Okhotsk Sea close to the eastern shore of Sakhalin Island. It is apparent, however, that the distribution was not uniform and that

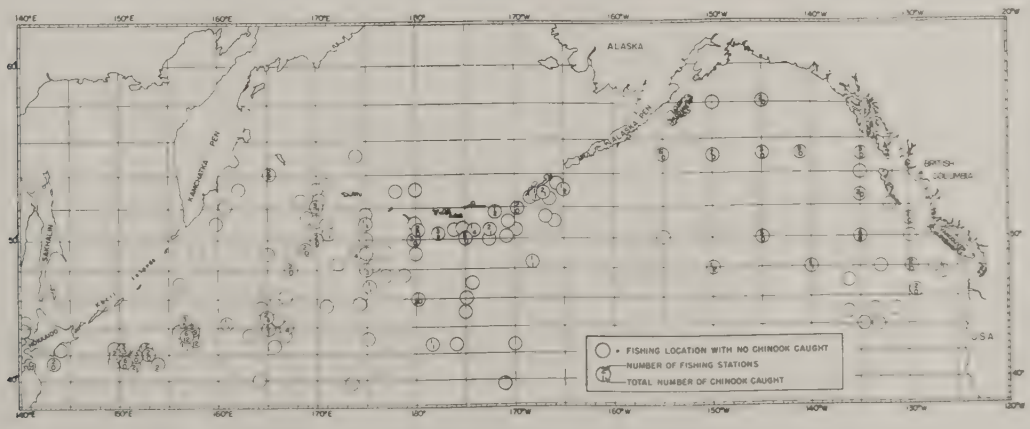

Figure 7. Gillnet fishing locations by research vessels of Canada, Japan and the United States in *May*, 1955 through 1962 combined.

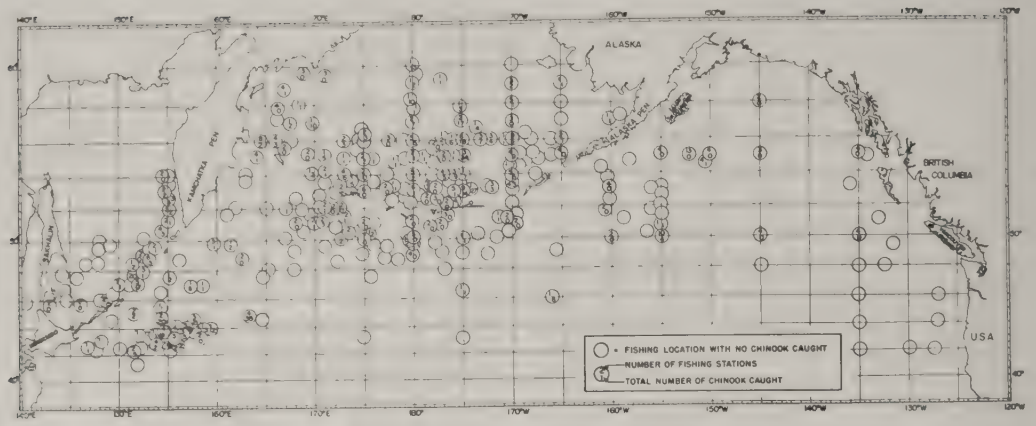

FIGURE 8. Gillnet fishing locations by research vessels of Canada, Japan and the United States in *June*, 1955 through 1962 combined.

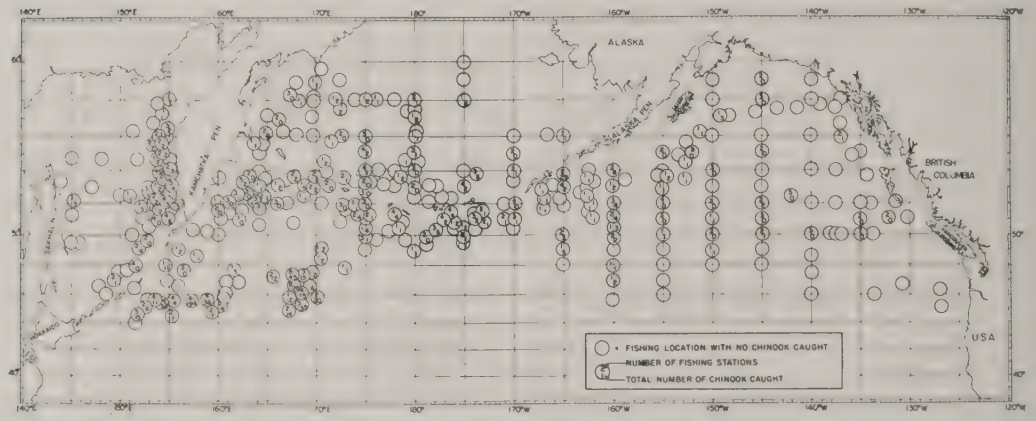

FIGURE 9. Gillnet fishing locations by research vessels of Canada, Japan and the United States in *July*, 1955 through 1962 combined.

FIGURE 10. Gillnet fishing locations by research vessels of Canada, Japan and the United States in *August*, 1955 through 1962 combined.

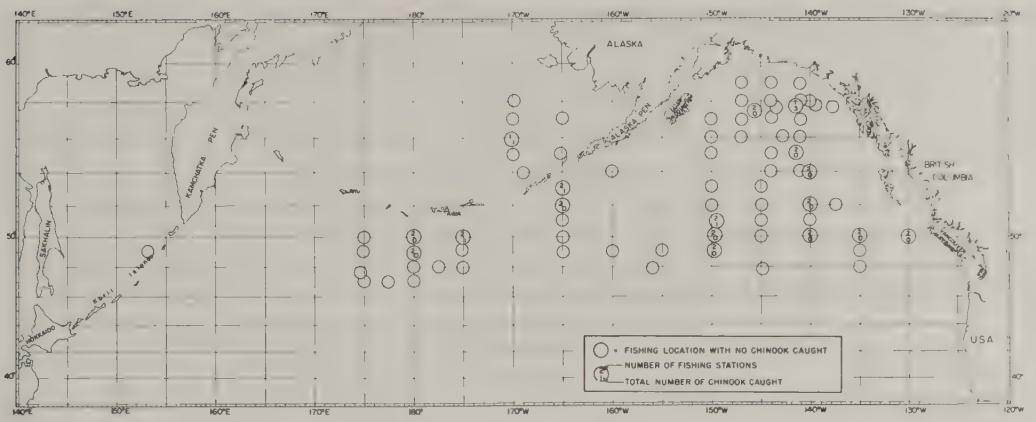

FIGURE 11. Gillnet fishing locations by research vessels of Canada, Japan and the United States in *September*, 1955 through 1962 combined.

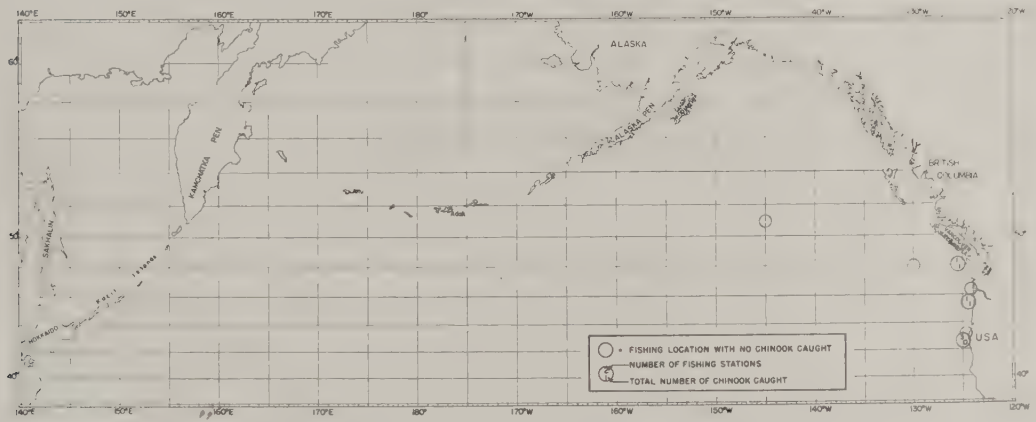

FIGURE 12. Gillnet fishing locations by research vessels of Canada, Japan and the United States in *October*, 1955 through 1962 combined.

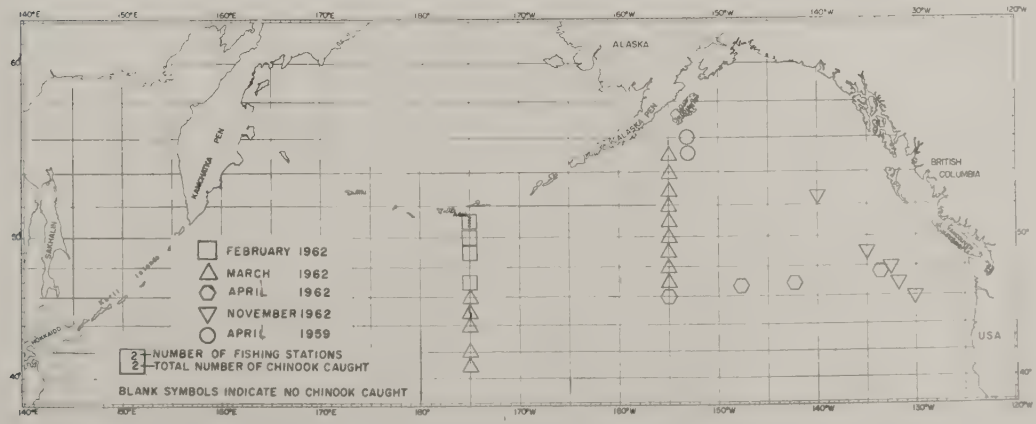

FIGURE 13. Gillnet fishing locations by research vessels of Canada, Japan and the United States in *February*, *March*, *April* and *November*, 1955 through 1962 combined.

the abundance of chinook varied during the spring and summer months at least.

Figure 13 summarizes gillnet fishing positions in the years 1955 through 1962 in all months other than May through October. All that can be said is that chinook may be found south of Adak in February and March.

Bering Sea

In the Bering Sea, data are too few for comment for periods earlier than the month of June (Figure 8). In June, chinook salmon were found from Bristol Bay to the Kamchatka Peninsula, northward from the Aleutian Islands to 60°N. They were apparently more abundant to the east of the 180° meridian than in waters to the west of 180°. Chinook were less abundant in July and August (Figures 9 and 10) in the central Bering Sea with the center of abundance located to the west of 180°. There may have been a similar movement east of 180°, but the data are too few for comment.

North Pacific Ocean

Gulf of Alaska to Unimak Island. No chinook salmon were caught in the area from the Gulf of Alaska to Unimak Island in May (Figure 7) except near the southern limit of fishing. They were caught in the southwest section of the area in June (Figure 8) and more to the north and northeast into the center of the Gulf in July (Figure 9). In both August and September, they were virtually absent from the center of the Gulf.

In July and August, chinook were relatively abundant west of Kodiak compared to east of Kodiak. This suggests that the Kodiak to Unimak area might be an area of transition between the Gulf of Alaska area and western areas. It is also apparent that chinook were virtually absent in a band or corridor running southeast from the Kenai Peninsula to the State of Oregon coast.

Unimak Island to Attu Island. In May, chinook were rather widely and sparsely scattered throughout the Unimak to Attu Island area south of the Aleutians. The few that were taken were generally rather close to the Aleutian Chain and in the westerly section of the area. In June (Figure 8), chinook were still rather widely scattered throughout the area and seemingly most abundant in the northwestern section. In July (Figure 9), chinook were apparently more abundant than in May and June and were found throughout nearly the whole of the area fished and as far south as fishing was carried out. While fishing was more extensive in August (Figure 10), most chinook salmon were taken in a band near the Aleutian Chain about four degrees of latitude wide. The only chinook caught in September (Figure 11) were in the same band.

Attu to Kuril Islands. In May (Figure 7), chinook were most abundant in the south and southeast parts of the general area, while none was caught near Kamchatka and only a few in the north near the Aleutian Chain. In June (Figure 8), chinook were apparently more abundant over a larger section in the southern part of the area than in May. The concentrations found in May near 165°E and 44°N were less apparent, perhaps due to the paucity of fishing in this section. A few were still taken close to the Aleutian Chain and a few were taken closer to Kamchatka. In July (Figure 9), the sections of principal abundance were in the southern part of the area. The greatest concentrations of chinook for all areas and all time periods were to the southeast. In August (Figure 10), limited fishing in the northwest section of the area resulted in catches throughout the section.

Okhotsk Sea

After fishing started in June (Figure 8), chinook salmon were found close to the western shores of the more northern Kuril Islands and the southwest Kamchatka Peninsula. None was caught in the few fishing positions in the southern central Okhotsk Sea area. In July (Figure 9), the area of principal abundance was along the west coast of the Kamchatka Peninsula over the whole north to south range that was fished. Abundance along the Kuril Islands appeared to be reduced from that in June. In August, chinook were apparently less abundant than in June and July along the west coast of the Kamchatka Peninsula. They were generally absent from the northern central and southern sections of the Okhotsk Sea, although they were caught to the northeast of Sakhalin Island. Fishing was discontinued after August.

Sea of Japan

In 1962, Japan undertook a limited amount of exploratory fishing in the Sea of Japan in April and May. One chinook was caught close to the western shore of Hokkaido Island.

Distribution and Abundance Described from Research Vessels Using Longlines

Research vessels using longlines were operated by Canada in 1962 in the Gulf of Alaska area and westward approximating the longitude of Unimak Island as shown in Figures 14 through 17. While Japan also operated research vessels using longline gear, only that area between the longitudes of Attu and the Kuril Islands was fished enough to add to knowledge of

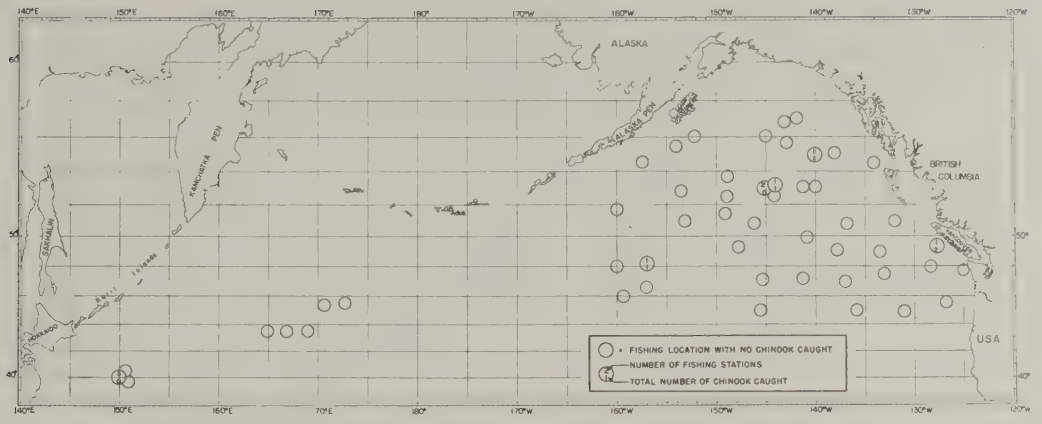

FIGURE 14. Longline fishing locations in *April* 1962 by research vessels of Canada and Japan.

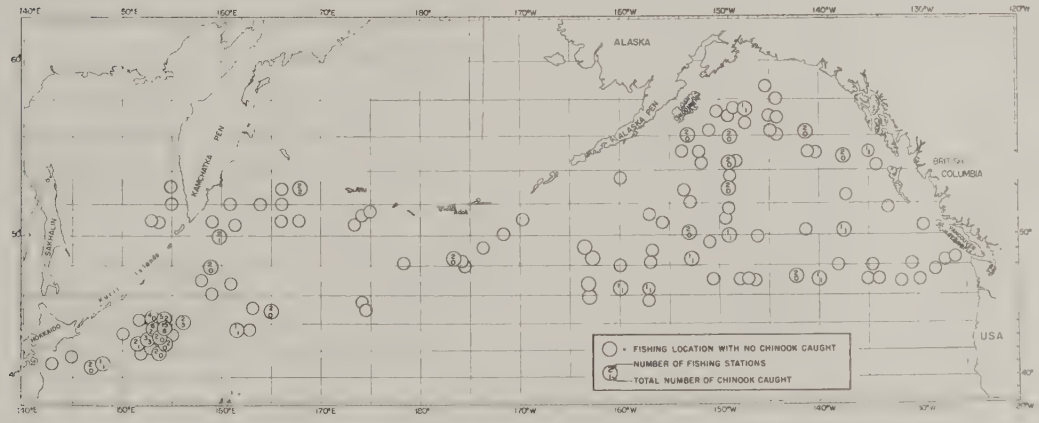

FIGURE 15. Longline fishing locations in *May* 1962 by research vessels of Canada and Japan.

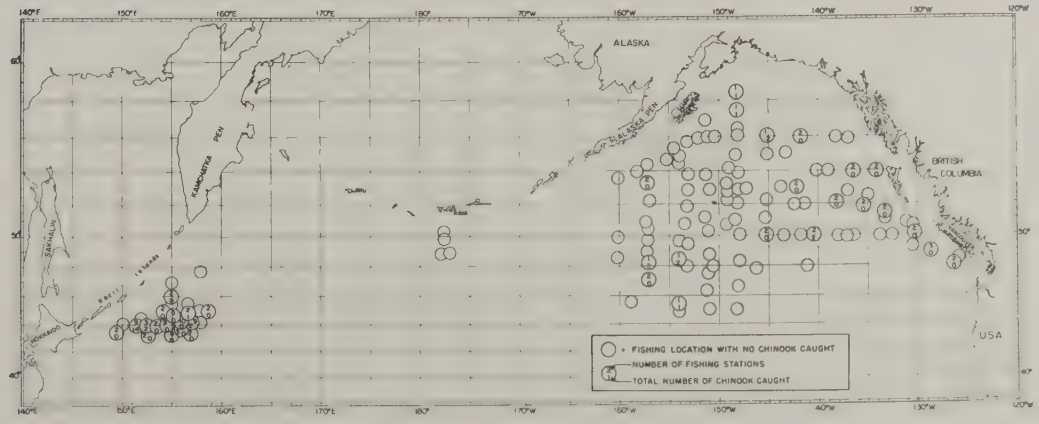

FIGURE 16. Longline fishing locations in *June* 1962 by research vessels of Canada and Japan.

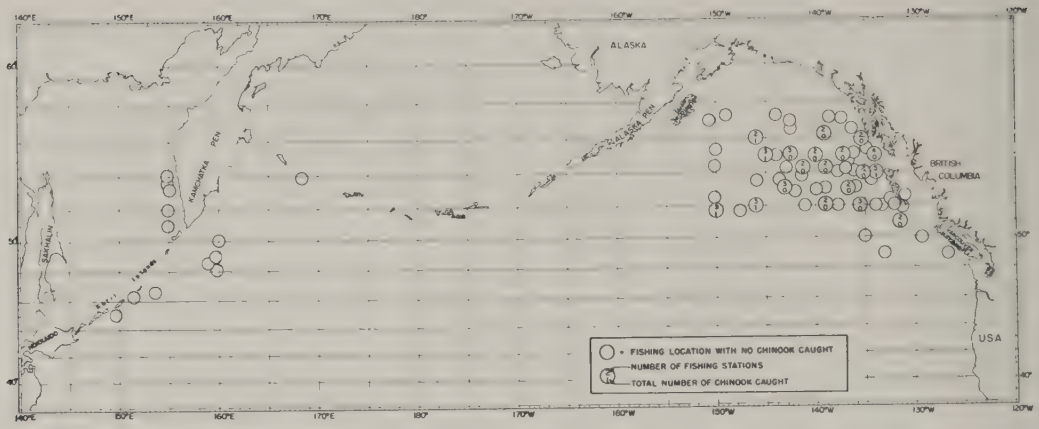

FIGURE 17. Longline fishing locations in *July* 1962 by research vessels of Canada and Japan.

distribution and abundance of chinook. The data in Figures 14 through 17 were taken from Neave *et al.* (1962) and Fisheries Agency of Japan (1962).

Gulf of Alaska

In April (Figure 14), a single chinook was taken southwest of Kodiak near the periphery of the area of fishing. Two others were taken to the northeast near the center of the Gulf. Figure 15, for May, shows that, aside from two chinook taken in the more northern periphery of the fishing area, no chinook were caught from the Gulf of Alaska and westward to about Unimak Island north of 51°N latitude. The six caught were taken west of 137°W longitude and south of 51°N latitude. In June (Figure 16), catches of chinook were similar in location to those in May, although the area fished was larger and fishing more intense. In July (Figure 17), the chinook taken in offshore waters were in the western and southern sections of the area fished.

Attu to Kuril Islands

Figure 15, for May, shows the principal area of chinook abundance to be eastward of Hokkaido Island near 155°E longitude. This was still the principal area of abundance in June. Longline fishing effort for earlier and later months was too scattered to add to the knowledge of distribution and abundance.

Comparison of Distribution and Abundance Based on Gillnet and Longline Catches of Research Vessels

Comparisons of the distribution of chinook salmon as described from longline and gillnet catches can be made only for the Gulf of Alaska area and the area eastward of Hokkaido. While the longline data are for 1962 only, it is assumed that they will serve as an index of chinook distribution for all years.

Gulf of Alaska

The chinook caught by longlines in April (Figure 14) established their presence in the Gulf of Alaska in that month where none had been taken by gillnets. Longline catches as shown in Figure 15 extended the May range further to the south and west and slightly eastward from that shown by gillnets (Figure 7). In June (Figure 16), longlines took chinook south and southwest of Kodiak and extended the range to the south of the areas fished by gillnets (Figure 8).

Attu to Kuril Islands

The area of highest abundance indicated by longline fishing and that indicated by gillnet fishing in the same season is generally the same in the region east of Hokkaido Island. Data for other parts of this general ocean area are not comparable due to the scattered longline fishing operations.

Distribution Described from Japanese Mothership Operations

Summaries of the number of chinook caught and catch per 100 tans by month and by areas for the combined years 1954 through 1961 by the Japanese mothership fisheries are given in Figures 18 through 21 as compiled from INPFC Statistical Yearbooks 1955 through 1961. These figures show chinook occurring from at least 46°N to 62°N latitude and from 175°W longitude (the eastern fishing boundary) to the Kamchatka Peninsula. No differences in distribution by months can be noted, since chinook were to be found in all the areas where the fleet operated in one or more of the years.

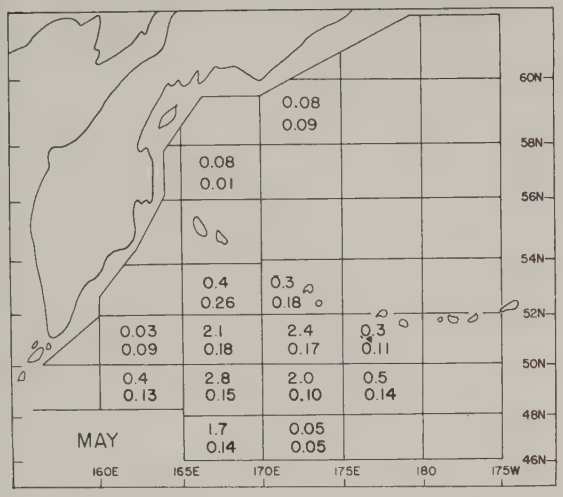

FIGURE 18. Thousands of chinook salmon caught (upper numerals) and catch per 100 tans (lower numeral) in the Japanese mothership fishery, *May*, 1954 through 1961. Data from INPFC Statistical Yearbooks 1954–1961.

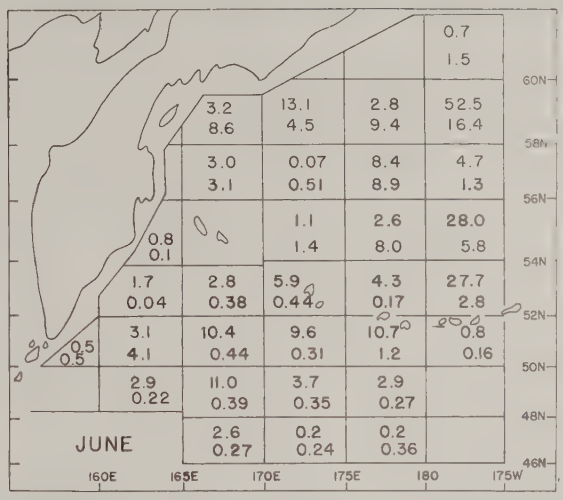

FIGURE 19. Thousands of chinook salmon caught (upper numerals) and catch per 100 tans (lower numeral) in the Japanese mothership fishery, *June*, 1954 through 1961. Data from INPFC Statistical Yearbooks 1954–1961.

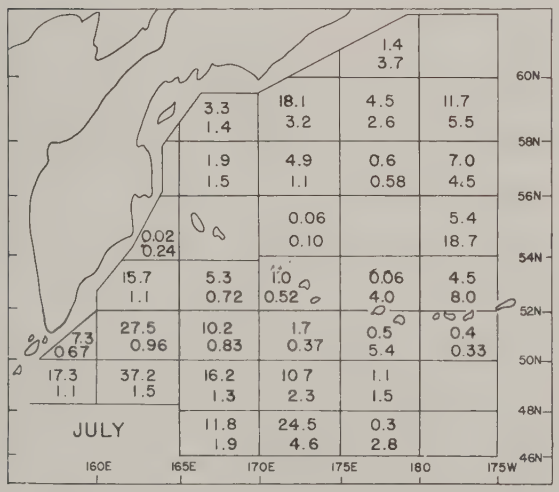

FIGURE 20. Thousands of chinook salmon caught (upper numerals) and catch per 100 tans (lower numeral) in the Japanese mothership fishery, *July*, 1954 through 1961. Data from INPFC Statistical Yearbooks 1954–1961.

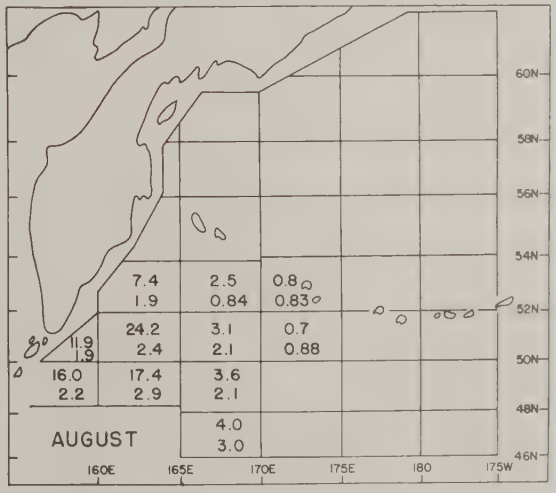

FIGURE 21. Thousands of chinook salmon caught (upper numerals) and catch per 100 tans (lower numeral) in the Japanese mothership fishery, *August*, 1954 through 1961. Data from INPFC Statistical Yearbooks 1954–1961.

The mothership data for the years 1952 and 1953 were also examined for indications that would broaden the knowledge of distribution. No information that would add to the conclusions for the combined years 1954 through 1961 was found.

Bering Sea data for interpretation of abundance in May and August are too few for evaluation, except to note that the area of principal catch was southeast of Kamchatka. The areas of largest catches in June centered around the Aleutian Islands between 175°E and 175°W longitude in the Bering Sea and southeast of Kamchatka (Figure 19). In July (Figure 20), the largest catches were made to the northwest toward

Oliutorski in the Bering Sea. Thus, a shift to the west is indicated in July followed by a further shift in August. In July, the chinook catches southeast of Kamchatka were higher than in all the other months and closer to coastal waters.

Chinook salmon were landed in the Okhotsk Sea in those years when a Japanese mothership fishery existed there. Fishing started in June south and west of the Kamchatka Peninsula, reached a peak in the same area in July, and ended in August.

The principal areas of abundance as shown by the catch per 100 tans were somewhat different from those shown by the catch in each area. In May, they were the same—southeast of Kamchatka (Figure 18). In June (Figure 19), the catch per 100 tans showed a greater abundance near 58°N latitude in the Bering Sea, as compared to the latitude of the Aleutian Islands shown by catches. Both catches and catches per unit of effort showed the center of abundance south of the Aleutians to be southeast of Kamchatka. While July catches in the Bering Sea were highest near Oliutorski, the catches per unit of effort showed that chinook were relatively abundant not only in that area, but also along the eastern fishing boundary. Catches and catches per unit of effort coincide reasonably southeast of Kamchatka.

Age, Sex and Maturity in Offshore Waters

The only data available for age and sex composition studies of chinook salmon are from Manzer *et al.* (MS1963) from samples taken in the Japanese mothership and landbased fisheries in 1960 (Table 10). (Research vessel data had not been tabulated nor collated at the time this manuscript went to press.) It should be recognized that these data are limited. They represent only one year and they concern only the fish caught, since no data are available as to either the effects of gear selectivity or the areas of sampling as related to the distribution of chinook salmon populations.

Ages and Sex Ratios

The age composition changed in all areas during the course of the fishing season (Table 10). Chinook salmon in their fourth year which had gone to sea in their second year (4_2's) were most abundant in the samples, followed by fish in their fifth year which also had left fresh water in their second year (5_2's). The data also indicate that as the season progressed the abundance of 5_2 chinook declined and that of 4_2's increased, 4_2's becoming predominant in the samples. By July and August, the abundance of 5_2's had decreased appreciably from the levels indicated in May and June except in the area west of 170°E where the decrease was not as great and interpretation limited by small samples in August.

In sex identification, 911 chinook salmon were identified as females and 948 as males, an approximately 50–50 ratio. The sex ratio was different, however, by (1) age groups, (2) by time of season within areas and (3) between areas. Excluding the landbased region data because of lack of sex-classified samples in the 5_2 age group, in the 4_2 age group, females comprised about 40 percent of the samples, compared to about 63 percent in the 5_2 age group.

In the east of 170°E-south of 52°N and west of 170°E areas, the percentage of females generally increased as the season progressed, while it decreased slightly in samples in the area east of 170°E-north of 52°N. The several small samples in the landbased fishery do not permit any interpretations of changes in sex ratio within the season. In the landbased fishery, 4_2 age group females were almost 51 percent of the samples, compared with 42 percent for all areas combined.

Average Length

The published research vessel data include length measurements from 33 chinook salmon reported by Powell and Peterson (1957) and a statement by Hartt (1962) to the effect that chinook caught for tagging purposes varied in size from 21 to 84 cm. These data are obviously inadequate for length analysis.

Dr. Hanamura of the Japanese Fisheries Agency supplied the data for Table 11 from the mothership fishery. These data show that females were almost always larger than males in all samples collected during May through August in the four years in which samples were taken. It is also apparent that for both males and females the average length per sample decreased in the period May through August in all years in all areas. The few exceptions were the 1958 samples from the Okhotsk Sea in June through July.

It should be noted in relation to the apparent greater sizes of females and their declining average length in relation to time, that males outnumbered females in May and June (combined year data) in all areas where significant sample sizes were obtained, except in the Bering Sea, where there were a few more females than males. In July and August, males again outnumbered females except in the Aleutian and Bering Sea samples. These data show that while males were generally more abundant in the samples, females were generally larger at any time during the fishing season in most areas. The reasons for these

TABLE 10. Age composition of samples of chinook salmon caught by mothership and landbased fisheries in 1960, with the sex ratio of age 4_2 and age 5_2 fish[1].

Area	Month	Age								Sample size	No. of 4_2's and 5_2's identified by sex
		3_2	4_2	4_3	5_2	5_3	6_2	6_3	7_3		
East of 170°E, South of 52°N	MAY										
	Percent		15		76		3		6		
	Number		5		26		1		2	34	
	% Male		80		27						11
	% Female		20		73						20
	JUNE										
	Percent		35		54		5	3	3		
	Number		32		49		4	3	3	91	
	% Male		72		49						47
	% Female		28		51						34
	JULY										
	Percent	1	85		9	5		1			
	Number	1	140		14	8		1		164	
	% Male		53		43						80
	% Female		47		57						74
	AUGUST										
	Percent		90		10						
	Number		7							8	
	% Male		57								4
	% Female		43								3
	Total males		105		37						142
	Total females		79		52						131
	% males		57.1		41.6						
	% females		42.9		58.4						
East of 170°E, North of 52°N	JUNE										
	Percent		51		38	6	1	4			
	Number		236		177	28	5	19		465	
	% Male		53		33						183
	% Female		47		67						230
	JULY										
	Percent	4	52		23	16		5			
	Number	2	29		13	9		3		56	
	% Male		55		31						20
	% Female		45		69						22
	AUGUST										
	Percent		74		26						
	Number		14		5					19	
	% Male		57		40						10
	% Female		43		60						9
	Total males		149		64						213
	Total females		130		131						261
	% males		53.4		33.8						
	% females		46.6		67.2						

Continued

TABLE 10. (Continued)

Area	Month	Age 3_2	4_2	4_3	5_2	5_3	6_2	6_3	7_3	Sample size	No. of 4_2's and 5_2's identified by sex
West of 170°E	MAY										
	Percent		23		45	2	13	13	4		
	Number		16		33	1	9	9	3	71	
	% Male		81		49						29
	% Female		19		51						20
	JUNE										
	Percent		38		43	4	6	7	2		
	Number		121		136	13	19	22	6	317	
	% Male		81		41						154
	% Female		19		59						103
	JULY										
	Percent	1	59	1	31	4		4			
	Number	7	398	7	209	27		27		675	
	% Male		59		36						310
	% Female		41		64						297
	AUGUST										
	Percent		89		11						
	Number		8		1					9	
	% Male		38								3
	% Female		62		100						6
	Total males		349		147						496
	Total females		194		231						425
	% males		64.3		38.8						
	% females		35.7		61.2						
Landbased, North of 45°N	JULY										
	Percent		84		11	1		4			
	Number		58		8	1		3		70	
	% Male		45								26
	% Female		55								32
	AUGUST										
	Percent	4	59		30	4		4			
	Number	1	16		8	1		1		27	
	% Male		44								7
	% Female		56								9
	Total males		33								33
	Total females		41								41
	% males		44.6								
	% females		55.4								

Continued

differences cannot be ascertained.

MIGRATION AND VERTICAL MOVEMENT IN OFFSHORE WATERS

While the material presented in Figures 7 through 13 suggests seasonal changes in horizontal distribution of chinook salmon, the deficiencies inherent in these data prevent any quantitative inferences concerning migration of chinook salmon on the high seas.

Powell and Peterson (1957) presented data which indicated that a greater percentage of chinook were caught in the lower two-thirds of a gillnet hanging approximately 20 feet into the water. No other data have been found concerning vertical migrations or distribution on the high seas. There is some information from North American commercial coastal trolling operations that chinook salmon may be further below the surface than coho salmon caught in the same area, but this information does not necessarily

TABLE 10. (Continued)

Area	Month	Age 3_2	4_2	4_3	5_2	5_3	6_2	6_3	7_3	Sample size	No. of 4_2's and 5_2's identified by sex
Landbased, South of 45°N	MAY										
	Percent		50		50						
	Number		6		6					12	
	% Male		33								2
	% Female		67								4
	JUNE										
	Percent		50			41	9				
	Number		11			9	2			22	
	% Male		64								7
	% Female		36								4
	JULY										
	Percent		84		12	3		1			
	Number		100		14	4		1		119	
	% Male		55								55
	% Female		45								45
	Total males		64								64
	Total females		53								53
	% males		54.7								
	% females		45.3								
All areas	Total males		700		248						948
	Total females		497		414						911
			1,197		662						1,859
	Percent males		58.5		37.5						
	Percent females		41.5		62.5						

[1] Data from Manzer *et al.* (MS 1963), Tables 40 and 42, and calculations based thereon.

apply to the offshore waters (Milne, 1955).

No data have been found that would allow any comment on distribution and abundance of chinook as affected by oceanographic conditions.

IDENTIFICATION AND SEPARATION OF STOCKS OR RACES

Only limited effort has been directed toward methods of identifying the continental origin of oceanic chinook salmon. Tagging for this purpose has indicated the probability of some intermingling of immature chinook from both continents (Figure 22). There were seven returns from over 900 chinook tagged west of 155°W longitude by Japanese and United States research vessels in the years 1956 through 1960 (INPFC, 1957–1961). With the exception of one chinook tagged and recovered by Japanese scientists, all were recaptured either one or two years after tagging. An examination of tagging data given in the INPFC Annual Reports (1956 through 1960) showed that about 94 percent of the chinook tagged by United States vessels was estimated to consist of immatures at time of tagging. Data on maturity were not available from the Japanese experiments.

The estimated 94 percent composition of immatures, the delay of one to two years in time of recapture, the apparent direction of migrations from a nearly common tagging point south of Adak and the apparent crossing of migration paths in the Bering Sea are interpreted as being evidences of the intermingling of immature chinook stocks from the two continents. The lack of data for chinook salmon tagged and recovered in the same year prevents any such statement for mature fish.

It is also apparent that the data are too few to allow any comments as to origin within continents. However, the two recoveries from the Yukon and the Columbia River systems indicate that a wide geographical range is quite possible.

DISCUSSION

The data used in this report were collected over nearly a century. They represent programs varying from small isolated pieces of research to coordinated

TABLE 11. Mean lengths of chinook salmon taken in areas fished by the Japanese mothership fishery[1].

			May		June		July		August		
Area	Year	Sex	Cm	No	Cm	No	Cm	No	Cm	No	Total
Aleutian	1957	F	78.3	58	61.7	205	55.2	93	—	—	
		M	70.7	100	59.1	227	54.1	87	—	—	
	1958	F	74.9	78	66.6	133	—	—	61.9	62	
		M	64.9	86	62.7	223	—	—	62.4	39	
	1959	F	82.5	5	67.1	113	60.1	198	—	—	
		M	59.8	13	61.7	186	58.7	167	—	—	
	1960	F	72.5	26	72.3	55	60.3	123	64.5	4	
		M	72.4	18	63.8	72	60.8	130	59.8	6	
	Total	F		167		506		414			1063
		M		217		708		384			1254
Bering Sea	1959	F	—	—	64.4	49	60.6	403	—	—	
		M	—	—	62.8	64	59.4	360	—	—	
	1960	F	—	—	61.5	420	59.9	49	66.1	11	
		M	—	—	59.8	392	58.8	48	62.8	19	
	Total	F				469		452			932
		M				456		408			883
Kamchatka-Kuril	1957	F	71.3	3	65.0	21	62.0	87	—	—	
		M	71.3	18	63	40	61.7	103	—	—	
	1958	F	72.1	168	68.6	848	62.0	1167	61.1	435	
		M	66.7	212	62.7	1200	61.2	1287	60.9	351	
	1959	F	78.1	50	65.8	115	62.6	143	—	—	
		M	64.1	93	61.2	228	61.2	170	—	—	
	1960	F	77.3	54	70.2	197	64.0	609	64.2	13	
		M	69.4	55	65.4	234	62.0	685	64.0	20	
	Total	F		275		1181		2006			3462
		M		378		1702		2245			4325
Okhotsk	1957	F	—	—	99.	1	64.4	14	—	—	
		M	—	—	68.1	27	60.5	46	—	—	
	1958	F	—	—	57.3	23	63.0	21	60.0	2	
		M	—	—	60.7	51	61.2	42	60.0	2	
	Total	F				24		35			59
		M				78		88			166
Landbased, North of J-S Treaty line	1960	F	—	—	—	—	60.1	42	59.9	21	
		M	—	—	—	—	61.8	36	60.7	22	
Landbased, South of J-S Treaty line	1960	F	56.0	5	71.9	13	58.5	61	—	—	
		M	69.1	8	63.5	11	59.9	80	—	—	
	Total	F									142
		M									157
	Total	F									5658
		M									6785

[1] Data supplied by N. Hanamura of the Japanese Fisheries Agency.

programs concurrently pursued by several fishery agencies. In spite of the elapsed time and the discontinuity in certain research efforts, some features are apparent that are pertinent to knowledge of the offshore distribution of chinook salmon.

Coastal tagging has shown that chinook salmon migrate in substantial numbers from the Columbia River, and even from as far south as the Sacramento River, to Alaskan and British Columbian waters. Consistent with this is the fact that the most northerly

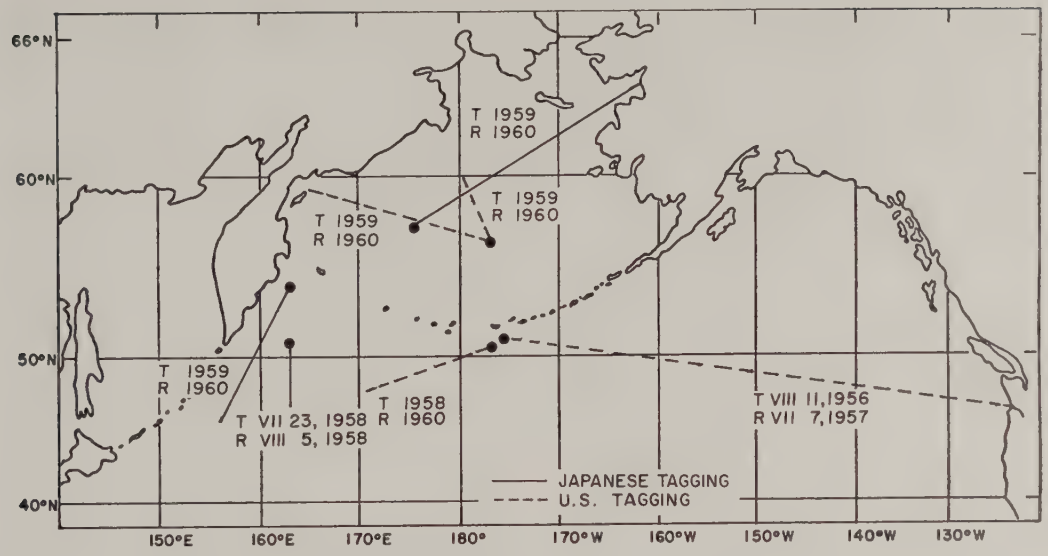

FIGURE 22. Recoveries of chinook salmon from tagging by Japanese and United States research vessels. Data from Godfrey (1961) and Hartt (1962).

recovery of a chinook salmon marked by fin excision was a fish from an early run Columbia River race. A difference in proportion of ocean type scales for chinook salmon leaving fresh water is indicated between southern and northern latitudes as shown from samples from the Taku and Yukon Rivers which were almost exclusively stream type scales, while in the area between the Taku and Sacramento Rivers some 70 to 90 percent were ocean type scales. (No samples were available to show where this change in composition occurred in relation to the geographical distribution of chinook salmon.) These factors suggest the possibility that the early run chinook of the Columbia River and elsewhere, which have a predominance of stream type scales, may mature in waters north (and west) of Cape Spencer. The fact that early run races of Columbia River chinook do reach Aleutian waters was established by the recovery in the Salmon River (an upper Columbia River tributary) of a fish tagged south of Adak as an immature. A possible migration route along the Aleutians for immature chinook salmon was noted from differences in catches between purse seine sets open to the east as compared with sets open to the west as well as an increase in abundance in June and July.

A limited number of scale samples from chinook taken by the Japanese mothership fishery failed to reveal a single instance of an ocean type scale. This may be due to the method of sampling, or even the possibility of a difference in method of interpreting scales. Until such time as additional data are found, present information indicates that any chinook that might be of North American origin and that might be taken in the Japanese mothership fishery would be from the more northern rivers or from early races of the more southern rivers.

It was noted that research vessels caught very few chinook salmon in a band running southeast from the Kenai Peninsula to the Oregon coast. Chinook have been caught both east and west of this band suggesting the possibility of a zone of delineation between populations. This apparent zone might be an artifact resulting from selectivity of the gear, a different vertical distribution of fish in this area, or even from the oceanographic conditions that existed. Still another possibility is that fishing in this band at other times of the year might have resulted in chinook catches. Whatever the reasons for the apparent existence of this band, they are not apparent in the data available.

SUMMARY AND CONCLUSIONS

This report has been based almost entirely on published information which was used without critical review or comment although some of the deficiencies and limitations were noted. The data were comparatively few, collected in widely scattered places and times, and usually collected for other purposes than

the objectives of this report. Therefore, the following conclusions are considered as tentative.

(1) Chinook salmon are found in North America from the Monterey Bay area to the Chukchi Sea. On the Asian coast, they occur from the Anadyr River area southward to Hokkaido. The larger populations are usually associated with the larger river systems.

(2) Total North American chinook catches greatly exceed those of Asia. In the period 1954 through 1961, the combined catches by U.S.S.R. and Japan have ranged from 96,000 chinook to 250,000 as compared with 2,456,300 to 3,664,200 chinook for the United States and Canada. Additional numbers were taken in North American sport fisheries.

The overall trend since World War II has been toward increased catches in both North America and Asia. Increased catches in Asia are attributable to additional fishing effort in the Japanese high seas fishery, starting in 1952, and increased Soviet coastal catches. The North American trend since 1946 toward increased catches is the resultant of declining catches in United States fisheries and increasing catches in British Columbia fisheries.

North American chinook catches, mostly from troll fisheries, start early in the spring and are much reduced after August. The specific dates are determined by regulations and characteristics of the populations in particular fishing areas.

Chinook salmon are occasionally taken in the Japanese coastal fisheries in November through January, although most are taken in April, May and June. In the Japanese mothership fishery, they are taken in the months of May through August with the peak usually occurring in July. Chinook catches on the East Kamchatkan coast are higher than those on the west coast and peak in June, although catches occur from May through August.

Since few escapement figures are available on either continent, it cannot be maintained with certainty that the population magnitudes are directly proportional to the catch.

(3) In North America, different river systems may characteristically have from one to several commercially fished runs of chinook, with southern rivers having more runs than northern rivers. Each such run may be composed of one or more races each destined for a particular spawning area. At the present time there are no demonstrated methods of identifying a particular race of chinook salmon prior to its arrival on its spawning grounds.

(4) In North America, chinook salmon migrate to the sea as yolk-sac fry, as fingerlings or yearlings, and sometimes at greater ages. They may pass through brackish water immediately or remain there for an indefinite period of time. Most apparently migrate towards the north, although some may migrate to the south and some may remain in the general area of the stream of their origin.

(5) North American scale samples showed that the age at maturity varies from two to seven years. In more southern waters, chinook salmon mature more commonly in their fourth and fifth years of life and in their fifth to sixth year of life in more northern waters. South of the Taku River, most scale samples were of the ocean type. In the Taku River and the Yukon River, all were of the stream type. Present data do not establish precise geographical areas of transition.

(6) For maturing chinook salmon, various tagging experiments show a positive southward migration in coastal waters off southeastern Alaska and British Columbia.

(7) Data from the Asian coast are either not presented in sufficient detail or are not available to establish the existence of various runs and races or describe variations in size of downstream migrants or the time of their migration. Coastal migrations, marine life history and age at maturity also are not adequately defined for Asian fish.

(8) The data from research vessels of Canada, Japan and the United States, and from the Japanese mothership fishery indicate that chinook may generally be found across the Pacific Ocean from at least 41°N latitude to the Aleutian Chain in the months of June through August. No chinook were caught in this period in a rather broad band running from the Kenai Peninsula southeast to the Oregon coast.

In June, chinook salmon were found in the Bering Sea westward from Bristol Bay to Kamchatka and northward from the Aleutian Islands to 60°N latitude. Greatest concentrations appeared to be in the central Bering Sea area. In July, the concentration apparently shifted to the westward of 180°, followed by a further westward shift in August. There was no September fishing in the area.

In May, chinook were found south of the Aleutians to 42°N latitude in the central North Pacific and to 40°N latitude close to Japan. The area of greatest abundance appeared to be south of the Komandorski Islands and east to 175°E longitude. The apparent

abundance in this area increased in June, reached a peak in July and declined in August. At the same time, the zone of greatest abundance apparently moved westward toward the coast of Kamchatka.

The pattern of a westerly movement of immature chinook with increased abundance in June and peak abundance in July was also observed south of and in close proximity to the Aleutian Islands at and west of Adak. This suggests a possible route by which chinook of North American origin might enter areas fished by the Japanese mothership fishery in some years.

(9) Since surface fishing gillnets, selective as to size of chinook caught, were used in both research and commercial operations, any conclusions reached on offshore distribution and abundance may apply only to the sizes of chinook caught in these surface waters and not to the total population which may have been present.

(10) Limited samples taken from the Japanese mothership fisheries in 1960 indicated that 4_2 chinook salmon were most abundant, followed by the 5_2's. All scale samples were of the stream type. The age composition changed with the season, older fish being more common earlier in the season.

While the sexes were evenly divided in the combined samples from the mothership and landbased fisheries, the sex ratio differed by ages, by time within areas and between areas. Males generally outnumbered females and the females were generally larger than the males in samples from the mothership fishery.

(11) No quantitative statements can be made on vertical or horizontal migrations, or on identification and separation of continental stocks, or on the degree of intermingling of mature and immature chinook salmon in offshore waters. However, the data show that migrations and intermingling do occur.

(12) There is an indication from one tag recovery that early run chinook races from the more southern North American rivers occur in waters of the central North Pacific Ocean as immatures.

ACKNOWLEDGMENTS

A number of Bureau of Commercial Fisheries scientists have reviewed this manuscript. Other reviewers included Mr. Donald H. Fry, California Department of Fish and Game; the State of Washington Department of Fisheries; Mr. J. M. Van Hyning, Fish Commission of the State of Oregon; Dr. William F. Royce and Mr. Allan C. Hartt, Fisheries Research Institute, University of Washington; Mr. Gary Finger, Alaska Department of Fish and Game; Mr. Harold Godfrey, Fisheries Research Board of Canada; and Dr. Shoichi Tanaka, Tokai Regional Fisheries Research Laboratory. While the author gratefully acknowledges their comments and suggestions, statements and any remaining errors are the responsibility of the author.

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The Benefits of Systematic Biological Collecting from Navigation Buoys

BY ARTHUR S. MERRILL [1]

Navigational buoys are placed at vantage points along practically all coastal and large inland waterways. They provide an artificial substrate near the surface for the attachment of species which ordinarily are bottom dwellers. When the buoys are brought ashore for periodic cleaning and servicing by the Coast Guard, the attached species of marine life become readily available for study. Systematic sampling of organisms, close observation of faunal assemblages, and diligent recording of the findings provide a wealth of scientific information.

I have observed and collected fouling organisms from navigation buoys for years, and have considered the varied opportunities for study such data provide. In this article I hope to illustrate some of the benefits of studying buoy animal communities and to suggest techniques that can be followed in these studies. In many cases I will use examples from data derived from my own studies of buoy material. Reference to the sea scallop, *Placopecten magellanicus,* will emphasize the significant role that material from buoys has played in increasing our general biological knowledge of one very important commercial species.

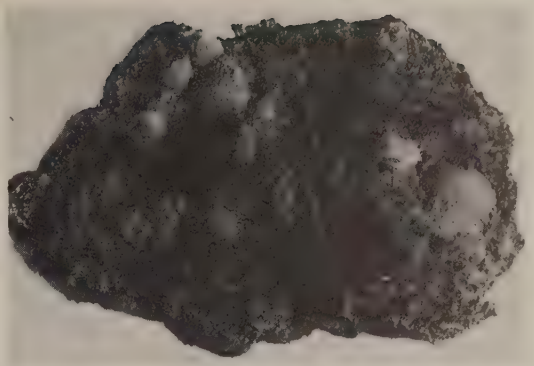

Fig. 1. A piece of iron rust removed from within the sheltered stabilizer tube of a buoy and allowed to dry. A number and variety of organisms can be seen still adhered in their original position.

Fouling Communities

A quantitative study of material collected from buoys along the coast will help determine the dominant fouling species, and at the same time will help establish geographical ranges and local zonation of many species. Usually only a few species dominate a buoy fouling community (see cover figure). The dominant species might well be different on buoys at the same latitude depending upon the precise location of these buoys. For instance, the community structure of the organisms found on a bay or harbor buoy will differ from that found on a buoy from open coastal waters. Equivalent differences in dominance are apparent at various latitudes along the coastline. In the northern coastal waters of Maine a plant such as *Laminaria* may dominate, while along the Cape Cod coast the blue mussel, *Mytilus edulis,* is often the dominant species. In southern waters several species of barnacles or oysters are common foulers. Buoys in protected shallow waters such as bays and estuaries are covered frequently with soft forms such as hydroids and fleshy tunicates. In northern waters goose barnacles are common on buoys located well offshore while further south they may occur on buoys closer to shore.

Vertical zonation is sometimes strikingly apparent on a buoy (cover figure). When such small scale zonation occurs two or more species will dominate, each at a different level. Aboard ship, as the winch reels in lengths of chain, the transition from an abundance of fouling to none at all is often clearly evident. For instance, the blue mussel normally aggregates in colonies along

[1] Bureau of Commercial Fisheries Biological Laboratory, Oxford, Maryland.

the coast in shallow water and cannot tolerate too great a depth. This is readily apparent when examining a chain from deep water on which *Mytilus* occurs. The number of mussels may decrease with increased depth, or may cease abruptly. A buoy is anchored by a mooring block, usually of metal or concrete. Studying the community structure on a mooring block adds to the complete vertical picture of species relationship.

Fouling assumes vast importance because of the destruction and inconvenience it causes. This is of considerable interest not only to the zoogeographer but, from an economic viewpoint, to governmental and private agencies whose vessels and marine installations are subject to fouling. As one means of combating fouling in general, anti-fouling paints continue to be tested in various marine waters by painting the surface of buoys and noting the effectiveness of various paint mixtures.

The first step in combating fouling is to learn what organisms are involved. In this respect collections from navigation buoys can play a useful and important role. A comprehensive monograph, "Marine Fouling and Its Prevention," [2] devotes an entire chapter to fouling species recorded from submerged objects throughout the world. The information listed was derived from thorough coverage of 244 publications, of which 48 have reference to buoys. The 837 species listed from buoys represent all the major groups. This is hardly an impressive number from a worldwide viewpoint; still it must be realized that most reports on buoy fouling do not emphasize the listing of species. Few people have attempted to identify and record systematically all species from individual buoys; or for that matter, even a particular group of organisms. Systematic identification of species could be a starting point for anyone wishing to participate in and contribute to the general understanding of the composition of fouling.

Communities, Succession, and Species Behavior

Ecologists will find that buoy material presents an excellent opportunity to study the organization and succession of communities and the adaptation of species. In addition, the settling habits and the mechanics of attachment of early postlarvae can be observed and studied.

Since buoys are surface vehicles, they serve also as "spat (larvae) collectors," and species with pelagic young in the upper waters are apt to settle on them. Many are species which adapt readily enough to life on buoys (Fig. 1) but are species which normally adhere to stones or other hard substrates on the bottom. The date a buoy is put into or taken out of the water is important as regards its faunal assemblage. This is because the reproductive habits of different species naturally determine which larvae are available at any particular time during the year. As colonies of attached species grow, the character of the buoy surface changes and in time free-living forms find shelter in the aggregates. The settlers which grow fastest may smother those whose growth is slower; but, if the slow growers do survive, they may eventually crowd out the early dominants. Thus, a buoy which has been long on station may display an extensively modified assemblage of organisms from that of a buoy out for a shorter period of time. The point to remember is that the community structure of a buoy is not static — all the interactions already mentioned, and others such as silting and severe variation in surface temperature, constantly contribute to molding and remolding the community.

In the offshore Cape Cod area the outsides of buoys are often covered with a wealth of life. These are mostly hardy forms able to withstand exposure and turbulence. Certain algae and barnacles, and the pelecypods *Mytilus edulis* and *Hiatella arctica* usually are found in abundance, and small gastropods such as *Mitrella lunata* and myriads of tiny shrimp live hidden among filamentous algae, bryozoa, or hydroids.

On the inside of a buoy stabilizer [3] the following temporal sequence is generally observed. Barnacles are among the first to settle, followed closely by certain of the algae, foraminifera, and bryozoa, blue mussels, and prickly jingle shells (*Anomia aculeata*). As the early settlers increase

[2] Prepared for Bureau of Ships, Navy Department, by the Woods Hole Oceanographic Institution, Contribution No. 580. Copyright 1952 by U. S. Naval Institute, Annapolis, Maryland.

[3] Navigation buoys come in many sizes and shapes according to the purpose for which they are used. In general, inshore buoys are made up of a float with or without a superstructure while buoys stationed further offshore have, in addition to a float and superstructure, a hollow, cylindrical stabilizer underneath (see Fig. 2).

At left is a photograph of a buoy taken from Cape Cod Bay. Zonation is apparent on this buoy — the upper part being fouled by algae, below which a belt of hydroids appears as light colored tufts, followed by an area of heavy, dark mussel-dominated fouling.

(Photograph courtesy of the Woods Hole Oceanographic Institution.)

in size, certain of the free-living annelids, crustaceans and echinoderms make their appearance. Secondary waves of spat, usually of barnacles, mussels, or jingle shells, are apt to settle on any available substrate including the shell surfaces of other early settlers.

Final settlement of organisms on the buoy is usually not at random. More will attach about slight protuberances such as bolt heads and welding ridges or in corners produced by metal flanges or collars. Examples of two extremes in settling habits are provided by the blue mussel and the sea scallop. The mussels settle at random with respect to one another, but soon tend to aggregate in persistent tight colonies. The scallop, on the other hand, while also settling at random, does not grow normally if in contact with other organisms including others of its kind and shows no tendency to form contact aggregations. Hence the sea scallop is not likely to be a dominant fouler.

Unusual phenomena are sometimes witnessed while collecting from buoys. In one case specimens of the soft-shell clam, *Mya arenaria*, a normally burrowing bivalve, were taken nestled in a growth of hydroids far up in a buoy stabilizer, having lived there for about two years. The importance of this find lies in the fact that this species not only lived and survived out of its normal habitat but grew faster than is usual. The collector is exposed to such odd and interesting discoveries with each buoy that he searches.

Collecting Data

If the investigator is able to spend some time aboard the buoy tenders he will be rewarded with many interesting observations denied to one who only examines buoys after they have been brought ashore. He can observe first-hand the ecological aspects of the living species. Fortunately, however, most buoy species are attached and usually still alive when a buoy is brought ashore. Many basic observations can therefore be made ashore as well as at sea.

After preliminary observations the buoys can be sampled according to the interests of the investigator. For quantitative studies, I restrict my collecting to the contents of a square foot of surface from a particular area on each buoy. For species studies I sometimes collect large numbers of individuals from several buoys. Another person might plan an experiment around an accessible species available through periodic removal from buoys. I have found that enough buoys are brought in each year to set up planned experiments involving the more common species from an area. And because live individuals of most attached forms can generally be obtained, anatomical or histological studies are practical.

Using the Data

Buoys are on station for known lengths of time, usually one to two years, although by accident or design some may be out for only a few weeks or months. Thus, when numerous buoys from an area have been examined, certain information such as definite limits of spawning seasons can be gathered for some species. It is obvious that single buoys out for short lengths of time can contribute especially good data on lengths of spawning seasons and on seasonal growth rates. Such buoys may also indicate seasonal variation of species and provide data for predicting seasonal abundances of certain larvae.

Length-frequency data of species collected from many buoys will fix modes and provide minimum growth rates. I say "minimum growth rates" because the precise time of setting of a species on a particular buoy cannot definitely be established even though the length of time a buoy is out is known. Generally, species that occur on buoys seem to grow more rapidly than in their natural habitats. This is probably a result of both temperature and current influences. Growth rates of

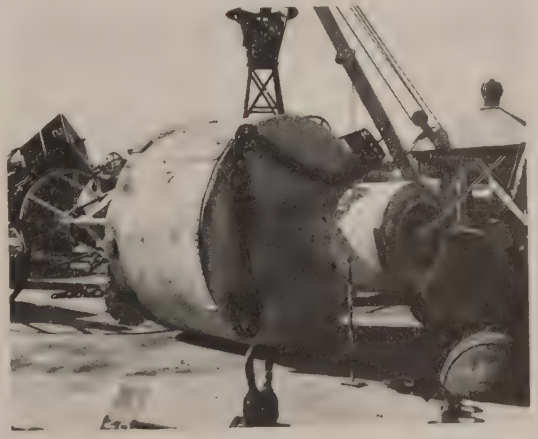

Fig. 2. Typical navigation buoy. Arrow indicates the sheltered inner portion of the stabilizer tube within which choice specimens can usually be taken.

organisms are known to vary with temperature of the water. Buoy organisms, being near the surface, are on the average exposed to warmer water than their fellows distributed on the bottom at varying depths. In like manner the circulation of the water is widely recognized as favoring the growth of sedentary species, and currents are known to be on the average more rapid at the surface than near the bottom, thereby making available more food materials. The biologist who makes a specific study of the effects of temperature, salinity, and tidal currents in relation to the growth of certain buoy species can verify or challenge the above statements.

I have found that the only satisfactory way to approach a growth problem is to compare material both from buoys and natural habitats if possible. In this way rates of growth can be established under different environmental conditions. Actually, we are doing this at the present time with the eastern oyster, *Crassostrea virginica*. The growth rate of oysters from buoys stationed at various locations in the Chesapeake Bay are being compared with the growth rates of those from the bottom. However, in the case of the sea scallop, *Placopecten magellanicus,* only occasional very young specimens are found in their natural habitat. What little is known of the early rates of growth for this species has been derived from numerous specimens taken from many buoys.

Lightships, stationed at intervals along the Atlantic coast, record certain hydrographic data daily, including bathymetric temperatures. Using these data, temperature tolerances can be approximated for species that normally settle and live in deep water but happen to settle and survive on buoys subject to greater temperature variation.

Under optimal conditions the shell surface sculpture of some organisms is more strongly expressed. Ideal conditions may exist on a buoy when a group of organisms, collectively, do not overpopulate the area; i.e., the buoy is not heavily fouled. In the Cape Cod area this condition sometimes is met when a buoy is placed in the water during the late fall months when fewer larvae are in the water to settle. If the buoy is removed in late spring or early summer the fall settlers have had a chance to grow rapidly without having been affected by the much heavier rash of late spring larvae.

The hollow inside of the buoy stabilizer is dark and offers a haven for many species (see arrow, Fig. 2). The enclosure decreases the stress of current action while at the same time the tube is continually flushed by wave action gently tossing the buoy. When examining buoys, I check the inside of the stabilizers very carefully for two reasons: 1, more kinds of organisms are usually represented there than elsewhere; 2, structural variations may be especially evident among the specimens found there. I have taken the Atlantic thorny oyster, *Spondylus americanus,* and the leafy jewel box, *Chama macerophylla,* both from tubes of surface buoys and from salvaged bottom wrecks at similar localities in the Florida Keys. The developing spines and foliations of buoy specimens are much more delicate and numerous than those from the usual habitat. I have found this to be true also with other species including several species of scallops which develop surface ornamentation.

Investigators are frequently handicapped by the lack of a series of specimens sufficient to show the extent of variation within a species. Because many thousands of a single species are often available from a buoy, variance within a population can easily be studied. Such studies are of special interest, since ecological factors are similar for all individuals, i.e., the microhabitat on the buoy is more uniform than the usual bottom environment. This is especially so when using material from buoys well offshore where silting is no problem.

Variation may be induced by environmental phenomena or it may be genetic. In a recent study of *Anomia aculeata,* some specimens were observed to have smooth shell surfaces, others spiny. It was possible to form a long series of specimens and see the intergrades between the extreme variants. However, of more interest and importance in this particular study is the fact that it was graphically demonstrated that the prickly jingle shell is a species whose full expression of inherent genetic variability for the character of spinosity might be expressed any time during their life history after metamorphosis. Without a great number of specimens from several buoy populations, these observations could not have been made.

The thousands of specimens of some species that may be obtained permit detailed description

of the changing morphology during early development. The sea scallop is a deep water form which so far has not been maintained through these early stages in the laboratory. With the aid of material from buoys, it has been possible to describe and figure fully the development of shell characters in the early stages of this species.

Theoretical Problem

Indirect issues such as the whereabouts of the spawning grounds, or the length of the larval period, or the direction and rate of speed of water currents can be given at least theoretical consideration as more and more information becomes available through studies of buoy material. However, a thorough background relative to the species in question is a prerequisite to the diligent consideration necessary in order to blend theory and fact. Some thought has been given this approach in an effort to learn more of the habits of the sea scallop. To illustrate: a buoy on station for seven months from October 1957 to May 1958 near the Nantucket Shoals Lightship (see chart, Fig. 3) contained a population of about 10,000 sea scallops, the modal size of which was 2.9 mm., the smallest being 0.5 mm., the largest 13.2 mm. Since none of these scallops could have been on the buoy longer than seven months, we know that they can grow as large as 13.2 mm. in a time not exceeding seven months after setting. Using temperature data collected by the nearby Lightship we find that the sea scallops had survived the coldest surface temperature of 37.3°F recorded for February 19, 1958. The data collected from the Nantucket Shoals Lightship buoy will allow a rather simple problem to be formulated: when and where were the sea scallops spawned which set on this buoy? Before attempting an answer one must have at least partial knowledge of the time of spawning, of the duration of the pelagic state, and of the direction and velocities of surface currents in the general area. Through field collecting we know that sea scallops spawned off Cape Cod during the autumn of 1958 from about September 15 to about November 15. Through laboratory experiments using various pelecypod species it is generally assumed that completion of the pelagic state takes from 10 days to 2 weeks, depending in part on water temperatures. Recent laboratory experiments indicate that the larval period for the sea scallop might be somewhat longer. Direction and velocities of currents have been plotted by oceanographers over a large area off the New England coast using, in part, information gathered by dropping drift bottles at prearranged points. Data from the returns indicate the greatest possibility of a current flow in this area during the late summer and fall months to be from a northerly direction (arrows in Fig. 3) at the average rate of 3 miles per day.[4] Thus, the minimum and maximum distance the pelagic larvae might have traveled can be approximated with a fair degree of certainty. Postulation of at least 2½ miles per day for 10 days for a total of 25 miles, and at most 3½ miles per day for 21 days, totalling 72½ miles, seems in order. In Fig. 3 circles represent the minimum and maximum distance possibly traveled by the larval scallops. We have a mass of data relative to scallop density north of the buoy which has been acquired through port interviews of fishing captains. These data indicate a heavy concentration of scallops at this time from 25 to 45 miles northeast of the buoy, with the heaviest concentration about 35 miles north-northeast. Other data from dozens of buoys have already allowed us to fairly well establish the growth rate of zero year scallops. The mode of six-month-old scallops from buoys averages 3.0 mm. which is

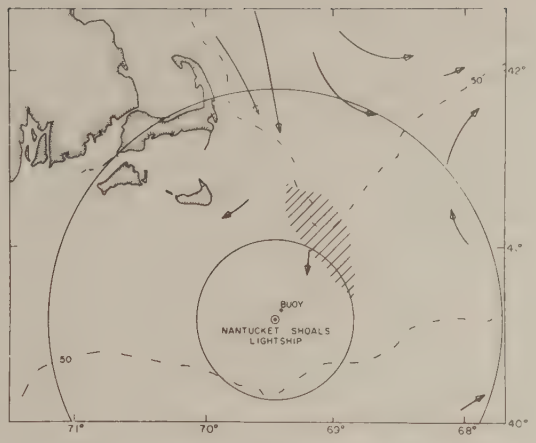

Fig. 3. Chart illustrating hypothetical problem. Circles represent possible minimum and maximum distance larval scallops traveled before settling. Hatched area positions heavy concentrations of adult scallops. Arrows indicate direction of current flow during the fall months in this area.

[4] Dean Bumpus, Woods Hole Oceanographic Institution, personal communication.

just over the mode in the Nantucket Shoals buoy. Since the buoy was placed on station October 10, the scallops must have settled on it almost immediately to attain this size. Allowing 3 weeks in the pelagic state the scallops probably spawned in the first part of October 1957 in the area about 35 miles north-northeast of the buoy. This conclusion, based in part on several suppositions, cannot be proved or disproved with certainty. It is simply a reasonable attempt to fill in some of the gaps in our present knowledge. Anyone with a sufficient background in a particular species and area will appreciate the intriguing aspects of such theoretical consideration.

A quote from the fouling monograph mentioned earlier (see footnote 2) might be appropriate in closing. This excerpt followed and summarized the development of the thesis that a given fouling community on a particular exposure follows a complicated pattern:

> The variation in detail which is possible through the operation of local and biotic factors is enormous. Only a beginning has been made on its analysis. Fortunately, the complexity of the local variations is somewhat offset by their accessibility for study, and progress in understanding them therefore can be expected.

The quote calls attention to the complexities of fouling and emphasizes the accessibility of material for study. This is particularly true of buoy material. Not only is material from buoys easily attainable but each buoy has its own community structure, an entity at the time of capture, available in a totality of related parts. Scientific contributions resulting from planned marine research using buoy harvests cannot help but further progress toward a better understanding of some of the biological intracacies involved.

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pp. 4–5

THE SURF CLAM FISHERY. Arthur S. Merrill, Bureau of Commercial Fisheries Biological Laboratory, Oxford, Maryland.

(Abstract)

The fishery for the Atlantic surf clam, *Spisula solidissima* (Dillwyn), was small before 1945 (except for bait), but has since developed rapidly into an important year-round fishery. For the 10-year period 1945–1954, total production of clam meats was about 75 million pounds. Production has increased threefold in the past decade; about 250 million pounds of meats were marketed in 1955–1964. Today the demand for surf clam meats is at an all-time high—about 38 million pounds were taken during each of the past 2 years. The meats are used principally for fried clams and in making fresh or canned chowder. Canned clam broth is a by-product. The meat also is excellent fish bait.

The surf clam ranges from Labrador to the Gulf of Mexico and is found in commercial quantities in certain areas of the Middle Atlantic bight from Long Island to Cape Hatteras. At present most of the catch is from a limited area between Pt. Pleasant and Cape May, New Jersey, although stocks north and south of this area were fished in earlier years. The clams are captured in depths less than 20 fathoms with special hydraulic dredges that plow into the substrate. The dredges are towed from 60- to 80-foot vessels which make 1-day trips. Several hundred bushels are taken each trip, to be shucked ashore.

Abundance and recruitment of clams, and location of commercial surf clam beds, are not adequately known. Therefore, members of the growing surf clam industry are properly concerned about the possible depletion of the resource. At the request of industry, the Bureau of Commercial Fisheries has recently undertaken studies of current and impending problems.

The Bureau's Exploratory Fishing and Gear Research Base at Gloucester, Massachusetts, is carrying out exploration and gear improvement. Several areas of the continental shelf have been minutely examined. Continued explorations are in progress to provide a comprehensive survey of the resources of the region. In addition, work has begun on the development of an instrument for detecting the presence of surf clams in the sediment and evaluating the efficiency of the commercial collecting gear.

The Bureau's laboratory at Oxford, Maryland, carries out biological research on surf clams. Fishery statistics collected from interviews at key ports on the coast are analyzed. Data are collected by periodic sampling of the surf clam grounds with a research vessel. These data are necessary to determine the production potential of the grounds, to establish the availability of present and pre-recruit year classes, and ultimately to offer recommendations on the number of clams that can be removed without the risk of depletion. An understanding of the population dynamics of the fishery also necessitates studies of growth and mortality. A comprehension of the basic biology of the surf clam is required to interpret growth

phenomena. Thus, studies of gametogenesis and spawning, culturing of larvae, and collecting of juveniles for research on early life history are needed. Furthermore, a knowledge is required of the factors involved with annual ring formation, and the influence of season, area, and other environmental conditions on length–weight ratios.

Research in the recently developed surf clam program is proceeding rapidly. Reports of progress are given at meetings such as this, at conferences with industry, and through publications.

Ancient Oyster Shells on the Atlantic Continental Shelf

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K. O. Emery
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Reprinted from Science, January 22, 1965, Vol. 147, No. 3656, pages 398-400

Ancient Oyster Shells on the Atlantic Continental Shelf

Abstract. *Shells of long-dead* Crassostrea virginica *are reported at 71 stations in depths of 14 to 82 meters. The depths exceed those of the estuaries where the species flourishes. Radiocarbon measurements indicate that the oysters were alive 8000 to 11,000 years ago. It is concluded that the oysters lived in lagoons or estuaries which became submerged when the sea level rose at the end of the latest glacial epoch.*

Many oyster shells were found in samples of bottom materials from the continental shelf between Cape Cod and Cape Hatteras. None of the samples contained living oysters. The oyster shells were identified as those of *Crassostrea virginica* (Gmelin) (*1*), the common edible species in estuaries along the Atlantic coast of the United States (*2*). The possibility that the shells were recently carried by currents from the mouths of present-day estuaries was not supported by the pattern of distribution. Nor was this possibility supported by the condition of the oyster shells, which, after they had dried, were observed to flake away easily as though the organic matrix in them had decomposed. Thus the depth, distribution, and character of the shells were suggestive of subfossils. Radiocarbon measurements of oysters from selected samples confirmed that the oysters were indeed ancient.

The oyster shells were found between Cape Cod and Cape Hatteras in dredge samples at 33 out of 113 stations of R/V *Delaware* (Cruise 60-7) in an investigation conducted by the U.S. Bureau of Commercial Fisheries during 1960 (*3*). A review of earlier data of the Bureau revealed the presence of the shells at one station of R/V *Albatross III* in 1955. During 1963, additional shells were found in large samples of bottom materials at 37 out of about 300 stations of R/V *Gosnold* between Cape Cod and Delaware Bay. These stations were occupied as part of a study of the geological history of the Atlantic continental shelf (*4*) being conducted by the Woods Hole Oceanographic Institution and the U.S. Geological Survey. The positions of all 71 stations where oyster shells were collected are given in Fig. 1. About 600 other bottom-sampling stations have been occupied by ships of the U.S. Bureau of Commercial Fisheries and the Woods Hole Oceanographic Institution east and northeast of Cape Cod, but no oyster shells were noted in that region. Samples south of Delaware Bay were largely restricted to the outer half of the continental shelf, thus accounting for the apparent restriction of oyster shells to that area (Fig. 1).

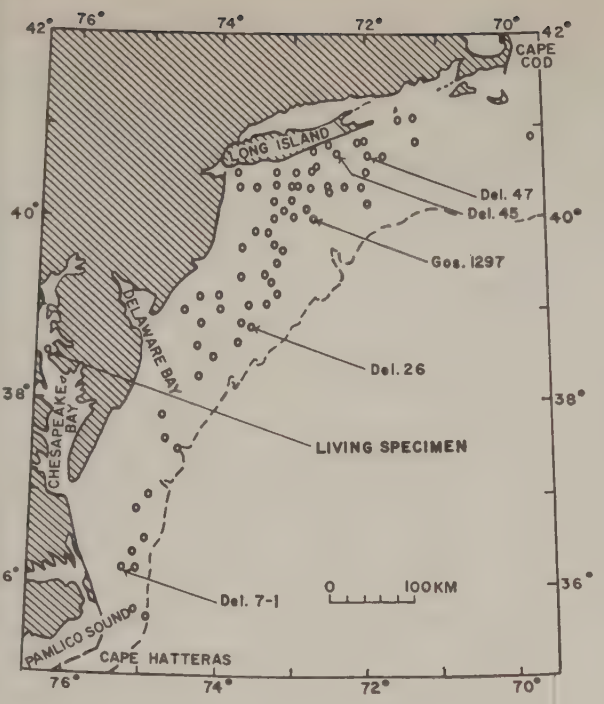
As shown in Fig. 2, the shells were found at water depths between 14 and 82 m, and there were some indications that they occurred in greater numbers at depths of about 38 m and 59 m. The water depths at all of the stations far exceed the depths at the intertidal or slightly subtidal positions of living oysters along the Atlantic coast. Compilation of the biological measurements showed that, on the average, the largest total numbers and weights of shells occurred at stations where the water depth was more than 30 m. Photographs of the bottom taken at the same time that the samples were collected aboard R/V *Gosnold* (*5*) showed the oyster shells resting on the surface of the bottom (Fig. 3) at only two stations. Evidently, most shells are buried in the sediment, where they were recovered from depths to 30 cm below the surface, the maximum depth of penetration of the large grab-sampler.

Studies of the geological history of the continental shelves of the world indicate that the shelves were exposed above sea level during the Pleistocene glacial stages (*6*). The latest such glaciation reached its climax about 18,000 years ago, after which the sea level gradually rose and allowed the shoreline to transgress the width of the continental shelf. Stages of transgression are recorded by drowned barrier bars and by terraces that commonly are four or five in number and occur throughout the world (*7*, *8*) as well as within the area of Fig.

Table 1. Ages of *Crassostrea virginica* estimated by radiocarbon dating.

Station No.	North latitude	West longitude	Depth (m)	Bottom type	Age (yr)	Lab. No.*
(Living specimen)†	38°33′	76°13′	2		Modern	W–1399
Del. 7–1	36°09′	75°20′	33	Sand and shell	8,130±400	W–1402
Del. 26	38°49′	73°39′	55	Sand and shell	9,780±400	W–1403
Del. 45	40°43′	72°25′	37	Sand	9,920±400	W–1400
Del. 47	40°40′	71°59′	51	Sand and shell	10,850±500	W–1401

* U.S. Geological Survey, Radiocarbon Laboratory. † Collected by Jackson in 1924 (*12*).



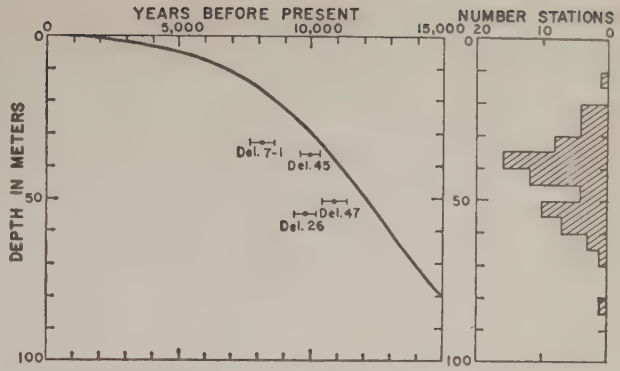


Fig. 1 (left). Positions of stations where shells of *Crassostrea virginica* were recovered in dredgings or grab samples of the bottom materials. The numbered stations are those from which specimens were selected for radiocarbon dating (Del., R/V *Delaware*) or where they were photographed (Gos., R/V *Gosnold*). Dashed line represents shelf break at a depth of about 150 m. Fig. 2 (above). Ages of shells (estimated by radiocarbon dating and shown as years before present) of *Crassostrea virginica* plotted against water depth at Delaware stations (numbered 7-1, 26, 45, and 47) where the specimens were collected (short horizontal lines). The curved line is the position of sea level during the past 15,000 years based upon a compilation of many radiocarbon dates by Shepard (*13*). The graph on the right shows the frequency of the present depths (below sea level) of all bottom samples containing the oyster shells (Fig. 1).

1 (*9*). Other terraces have been buried under later sediments so that they can be detected only by deep borings or by continuous seismic profiling. Examples have been found in the area of Fig. 1 (*10*). Also relict from shallow water during the transgression are sediments which are coarser grained than those now being deposited nearer shore and which commonly are stained by iron (*8*). These phenomena have been interpreted as indicating the presence of former lagoons and estuaries on the present continental shelf and that the features became submerged as the sea transgressed and deepened (*11*).

Shells recovered from the Atlantic continental shelf in the area of Fig. 1 at depths of 145 to 165 m have been identified as shallow-water (less than 40 m) forms (*6*, *10*). Attempts to estimate the age of these shells by radiocarbon dating revealed only ages in excess of 30,000 years. Valves of *Crassostrea virginica* are better than most shells for radiocarbon dating because their thickness provides resistance to solution and disintegration. The depths at which the oyster shells were found (Table 1) are less than those of the previously investigated shells, suggesting that the ages of the oyster shells might be within the range of the radiocarbon method. Shells were selected on the basis of station position and depth (Figs. 1 and 2), weight of the valves (50 to 200 g), and lack of weathering, recrystallization, and encrustation. Specimens from four stations (Fig. 1) were chosen for analysis at the radiocarbon dating laboratory of the U.S. Geological Survey. In addition, the shell of a specimen collected alive in 1924 (before testing of nuclear weapons) from shallow water in Chesapeake Bay (*12*) was investigated in order to determine whether a correction to the ages estimated by radiocarbon dating should be applied because of the radiocarbon age of the lagoonal or estuarine waters in which the oysters must have lived. The results (Table 1) reveal that the living specimen is modern (about zero age) for the method; thus no age correction is necessary.

Ages of the shells from the continental shelf range from 8130 to 10,850 plus or minus 400 or 500 years. As shown in Fig. 2, these ages are 1000 to 3000 years less than the ages given by an average curve of sea level plotted against past time (*13*). Conversely, the water depths are 10 to 30 m greater than those of the curve. A possible cause of decreased apparent age is the inclusion of the remains of boring organisms or incrustations composed of calcium carbonate younger than the shell itself despite precautions taken to avoid using shells that showed this form of contamination. Only a slightly better fit of the oyster shell data to the curve would be provided by adjusting the points to account for a possible average water depth of 6 m (*14*) at the sites where the oysters lived. Extensive reworking and movement of the shells eastward into deeper water after the growth site was submerged is considered unlikely because the shells were more abundant and heavier at the deeper stations. Postdepositional tectonic movement of the continental shelf may be a factor, but

Fig. 3. Photograph of the sea-bottom at station Gos. 1297 (R/V *Gosnold*), south of Long Island (39°59.4'N; 72°45.4'W; 56 meters). Two empty shells of *Crassostrea virginica* (bottom left and upper right corners) lie on the medium- to coarse-grained brown sand. The photograph covers a bottom area of about 40 by 40 cm.

evidence is incomplete. In spite of these uncertainties, the points shown in Fig. 2 are probably as good as most of those for low sea levels about 10,000 years ago; in fact, they fall within the scatter of points based on many kinds of materials through which the curve of Fig. 2 was drawn by Shepard (*12*).

Medcof (*15*) reported several age determinations of oyster shells; one shell, aged 10,600 ± 130 years, came from Georges Bank (42°05′N; 67°15′W) and was at a depth of 53 m of water. Another, aged 6850 ± 100 years, came from Northumberland Strait in the Gulf of St. Lawrence (46°00′N; 62° 37′W), from a depth of 37 m. These results (*16*) corroborate and seem likely to extend our own findings.

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References and Notes

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17. We are indebted to R. L. Edwards, R. H. Meade, R. L. Wigley, A. C. Redfield, and J. C. Medcof for critical reading of this manuscript. Contribution No. 1530 of Woods Hole Oceanographic Institution.

18 December 1964

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MOLLUSKS NEW TO SOUTH CAROLINA

By ARTHUR S. MERRILL[1] and RICHARD E. PETIT[2]

Certain species collected in beach drift along the shores of South Carolina, and other material brought to us by cooperating shrimp fishermen in the past, led us to suspect that many of the mollusks from the Caribbean province inhabit these waters but have never been reported in the literature due to the lack of concentrated collecting. Therefore, we decided to do extensive shore collecting and offshore dredging when possible, in an effort to define properly the fauna. This work has resulted in many range extensions to South Carolina, some of which are here reported.

Many of our range extensions are major ones, commonly extending known ranges northward from southeast Florida, over four hundred miles. These records from South Carolina are particularly important because this state lies between Cape Hatteras and southern Florida, areas where the molluscan fauna has been much more extensively defined. One has only to check the "specimens examined" sections of *Johnsonia* to realize the lack of specific locations for species between these areas. Most of the North Carolina records are from the old *Albatross* dredgings, and those from southern Florida are largely from the McGinty dredgings. Until our recent work, little dredging has been done off the South Carolina coast since the *Albatross* made a few deep water stations in 1885.

We are fortunate to have dredgings from 18 stations offshore to supplement our shore collecting. Our first series of dredgings consisted of a transect of 12 stations off McClellanville, S. C. made in July 1963 aboard the shrimp boat, *Miss Kim,* at depths

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of 1 to 64 meters. Another transect of six stations off Cape Romain, S. C. followed in November 1963 using the Woods Hole Oceanographic Institution R/V *Gosnold* at depths of 36 to 268 meters. A 30-inch Digby scallop dredge, lined with ½ inch mesh, was towed at all stations.

This paper is the first of several in which we will report range extensions to South Carolina. We will also reaffirm or clarify older records when this seems necessary.

In determining the distribution of the mollusks we have consulted the usual references which contain such information. These include, in all cases, Dall (1889), Mazyck (1913), Johnson (1934), Abbott (1954 and 1958), Warmke and Abbott (1961), as well as all *Johnsonia* monographs and all volumes of the *Nautilus*.

At least one collection of each species mentioned in this report has been placed in the Museum of Comparative Zoology, except when only one specimen of a species has been taken. Such specimens are being retained for the purpose of comparison until we have completed our studies, at which time they will also be deposited at the MCZ.

We acknowledge the cooperation of the Woods Hole Oceanographic Institution and Dr. K. O. Emery, geologist and chief scientist of *Gosnold* Cruise no. 33, for allowing us several hours of ship time for the purpose of dredging off Cape Romain, S. C., when the vessel was passing through these waters taking echo soundings and seismic profiles.

We are indebted to the following people for assistance in identifying or confirming identification of species within their special interests: Drs. William J. Clench, Ruth D. Turner, Kenneth J. Boss, Harold A. Rehder, Joseph P. E. Morrison, Joseph Rosewater and Alex A. Olsson.

We particularly wish to thank Drs. R. Tucker Abbott and Robert Robertson for examining some of our material and also for reviewing our manuscript.

Gastropoda

Calliostoma (*Kombologion*) *marionae* Dall.

Calliostoma marionae Dall 1906, Nautilus, *19:* 131.

One large fresh fragment, about two-thirds of body whorl, 21 mm. in diameter, dredged off Cape Romain, S. C. (N. Lat. 32°-

49.0′; W. Long. 78°16.3′), in 65-80 meters, on Nov. 27, 1963. Another fresh fragment dredged nearby.

Previous northernmost record, "off St. Augustine, Fla." (Clench and Turner, 1960, p. 51).

Turritella exoleta (Linnaeus)

Turbo exoletus Linnaeus 1758, Syst. Nat., ed. 10, p. 766.

Live adult specimens, reaching 35 mm. in length, dredged off Cape Romain, S. C. (N. Lat. 32°49.4′; W. Long. 78°16.7′), in 55 meters, on Nov. 27, 1963; also found to be common in other nearby dredgings.

Previously recorded as far north as, "south half of Florida" by Abbott (1954, p. 141).

Siliquaria squamata Blainville

Siliquaria squamata Blainville 1827, Dict. Sci. Nat., *49:* 213.

One fresh dead specimen, about 90 mm. in length, dredged off Cape Romain, S. C. (N. Lat. 32°49.4′; W. Long. 78°16.7′), in 55 meters, on Nov. 27, 1963. Also, a smaller dead specimen from a nearby station.

Northernmost range previously reported, off Palm Beach, Fla. (McGinty and McGinty, 1957, p. 39). Bathymetric range also extended, being previously reported from 80-163 fathoms [ca. 150-300 meters] (Johnson, 1934, p. 105).

Epitonium (Asperiscala) apiculatum (Dall)

Scala apiculata Dall 1889, Bull. Mus. Comp. Zool., *18:* 310.

Four adult specimens, largest measuring 10 mm. in height, collected in beach drift at low tide at Ocean Drive Beach, S. C., in Feb. 1960. Also, one small broken shell dredged off Cape Romain, S. C., Nov. 27, 1963, in 46 meters.

Clench and Turner (1952, p. 292) remark that this species is, "known only from North Carolina." However, their *Albatross* station 2619 record is in fact due east of a point about 5 miles south of Myrtle Beach, S. C. Our record from Cape Romain is a minor range extension; our primary purpose here is to point out that this species reaches a much larger size (over twice as large) than has been reported, and to correct the impression that North Carolina is as far south as it ranges.

It might be well to point out at this time that we have collected *Epitonium (Asperiscala) championi* Clench and Turner at Myrtle Beach, S. C. which Clench and Turner also report as ranging

south to North Carolina, although their Frying Pan Shoals record is probably well into the latitude of South Carolina.

Epitonium (Epitonium) krebsii (Mörch)

Scala krebsii Mörch 1874, Vidensk, Medd. Naturhist. Forening i Kjöbenhavn No. 17, p. 252.

One fresh dead specimen, 10.6 mm. in length, dredged off Cape Romain, S. C. (N. Lat. 32°43.2′; W. Long. 78°09.7′), in 176 meters, on Nov. 27, 1963.

Previous northernmost record, "off Palm Beach, Fla." (Clench and Turner, 1951, p. 258).

Crucibulum auricula (Gmelin)

Patella auricula Gmelin 1791, Syst. Nat., ed. 13, p. 3694.

One fresh dead specimen, 18 mm. in greatest diameter, dredged off McClellanville, S. C. (N. Lat. 32°42.4′; W. Long. 79°06.2′), in 27 meters, on July 2, 1963.

The most northern record listed by most authors is "West Florida," probably as a result of Dall's (1889, p. 152) specific designation of Cedar Keys, Fla. as northern extreme range.

Tugurium (Tugurium) caribaeum (Petit de la Saussaye)

Xenophora caribaea Petit de la Saussaye 1856, Journ. de Conchyl., *5:* 248, pl. 10, fig. 1-2.

One fresh dead adult specimen, 64 mm. in greatest diameter, dredged off Cape Romain, S. C. (N. Lat. 32°43.2′; W. Long. 78°09.7′), in 176 meters, on Nov. 27, 1963.

Previously recorded from the Florida Keys by Johnson (1934, p. 96) and others, but not recorded from the mainland of the United States by Clench and Aguayo (1943, p. 5). However, they did remark that Dall (1889) considered North Carolina as the northern range of this species, but noted that Dall's material apparently included specimens of *T. longleyi* Bartsch, and for that reason they limited the northern range to Cuba. Also reported from off Palm Beach, Fla. (McGinty and McGinty, 1957, p. 40).

Sigatica semisulcata (Gray)

Natica semisulcata Gray, 1839 [in] Beechey, The Zool. of Capt. Beechey's Voyage, p. 136.

Two fresh dead adult shells collected on beach at Ocean Drive Beach, S. C., and one additional specimen inhabited by hermit crab found in old net brought up from 7 meters off Ocean Drive

Beach, S. C.; all collected in the fall of 1959.

Previous northernmost record, Jupiter Inlet, Fla. (Dall, 1889, p. 154).

Cypraea spurca acicularis Gmelin

Cypraea acicularis Gmelin 1791, Syst. Nat., ed. 13, p. 3421.

Several fresh dead to moderately worn adult specimens dredged off Cape Romain, S. C. (N. Lat. 32°49.4′; W. Long. 78°16.7′), in 55 meters, on Nov. 27, 1963; also taken commonly in other nearby dredgings, some badly worn.

Previously recorded as far north as "south half of Florida" by Abbott (1954, p. 180).

Cymatium (Septa) pileare Linnaeus

Murex pileare Linnaeus 1758, Syst. Nat., ed. 10, p. 749.

One fragment of body whorl and outer lip dredged off Cape Romain, S. C. (N. Lat. 32°49.1′; W. Long. 78°16.3′), in 65-80 meters, on Nov. 27, 1963.

Johnson (1934, p. 114) lists the range of this species in the western Atlantic as, "Florida Keys and the West Indies." Abbott (1954, p. 195) extends the range to North Carolina, but Clench and Turner (1957, p. 218) in the latest monograph to include this species shows northernmost record only to Jupiter Inlet, Fla.

Cymatium (Septa) krebsii (Mörch)

Triton krebsii Mörch 1877, Malakozoologische Blätter, *24:* 30.

One fresh dead specimen, 27 mm. in length, dredged off Cape Romain, S. C. (N. Lat. 32°49.4′; W. Long. 78°16.7′), in 55 meters, on Nov. 27, 1963.

Previous northernmost range, "off Delray Beach, Fla." (Clench and Turner, 1957, p. 221).

Cymatium (Monoplex) parthenopeum (von Salis)

Murex parthenopeus von Salis 1793, Reisen in versch. Prov. Konigreich Neapel, *1:* 370, pl. 7, fig. 4.

One live specimen, 93 mm. in length, taken by trawler *Miss Key*, 40 miles off McClellanville, S. C., in 75 meters, in June 1962.

Previous northernmost range in western Atlantic: U. S. coast, "south end of Lake Worth, Fla."; Bermuda (Clench and Turner, 1957, p. 230).

Cymatium (Linatella) poulsenii (Mörch)

Triton (Linatella) poulsenii Mörch 1877, Malakozoologische Blätter, *24:* 33.

One fresh dead specimen, plus several fragments, dredged off McClellanville, S. C. (N. Lat. 32°31.2′; W. Long. 78°51.0′), in 46 meters, on July 3, 1963.

Previous northernmost range, "off Palm Beach, Fla." (Clench and Turner, 1957, p. 200).

To complete the list of species of the genus *Cymatium* now known from South Carolina we include the following: A juvenile, *Cymatium (Ranularia) caribbaeum* Clench & Turner 1957, was collected alive from a navigation buoy located off Port Royal, S. C. (Merrill, 1962). A juvenile, *Cymatium (Cabestana) labiosum* (Wood) 1828 was also taken from a navigation buoy from off Cape Romain, S. C., by the senior author in 1948. This record appears in the monograph by Clench & Turner (1957) on page 222. We have taken *labiosum* from off Cape Romain in our recent dredgings.

Bursa thomae (Orbigny)

Ranella thomae Orbigny 1842 [in Sagra], Hist. l'Ile Cuba, *2:* 164, Atlas, pl. 23, figs. 23, 24.

One live 20 mm. adult dredged off Cape Romain, S. C. (N. Lat. 32°43.2′; W. Long. 78°09.7′), in 176 meters, on Nov. 27, 1963.

Previous northernmost record from Western Atlantic, off Palm Beach, Fla. (Abbott, 1958, p. 57).

Murex cabritii Bernardi

Murex cabritii Bernardi 1859 ("1858"), Journ. de Conchyl., *7:* 301, pl. 10, fig. 3.

A fresh fragment of a large shell, dredged off McClellanville, S. C. (N. Lat. 32°31.2′; W. Long. 78°51.0′), in 46 meters, on July 3, 1963.

Dall (1889) lists this species as occurring north to Cape Hatteras, N. C. However, Johnson (1934) gives northernmost range as Cedar Keys, Fla., and Clench and Farfante (1945, p. 5) show Pompano, Fla., for their northernmost record. Abbott (1954) also restricts the range to Florida.

Murex rubidus F. C. Baker

Murex messorius var. *rubidum* 'Dall' F. C. Baker 1897, Trans. Acad. Sci. St. Louis, 7 (16): 377.

One medium-sized live specimen, 30 mm. in length, dredged off Cape Romain, S. C. (N. Lat. 32°49.4′; W. Lat. 78°16.7′), in 55 meters, on Nov. 27, 1963.

Previous northernmost record, Lake Worth, Fla. (Clench and Farfante, 1945, p. 9).

Pterynotus pygmaeus Bush

Murex (Pteronotus) pygmaeus Bush 1893, Bull. Mus. Comp. Zool., *23:* 213, pl. 1, figs. 3-4.

One specimen, 14.4 mm. in length, dredged off Cape Romain, S. C. (N. Lat. 32°43.2′; W. Long. 78°09.7′), in 176 meters, on Nov. 27, 1963.

Previously known only from the holotype which was dredged from *Blake* Station 319, off Charleston, S. C. (N. Lat. 32°25′; W. Long. 77°42′30″), in 262 fathoms [480 meters].

Drupa (Morula) nodulosa (C. B. Adams)

Purpura nodulosa C. B. Adams, 1845, Proc. Boston Soc. Nat. Hist., *2:* 2-3.

Two live specimens, dredged off McClellanville, S. C. (N. Lat. 32°31.2′; W. Long. 78°51.0′), in 46 meters, on July 3, 1963.

Previous northernmost record, "Biscayne Bay, Fla." (Abbott, 1958, p. 63).

Coralliophila aberrans (C. B. Adams)

Purpura aberrans C. B. Adams, 1850, Contrib. to Conch., No. 4, pp. 58-59.

One very fresh, 9.4 mm. specimen, dredged off Cape Romain, S. C. (N. Lat. 32°43.2′; W. Long. 78°09.7′), in 176 meters, on Nov. 27, 1963.

Previous northernmost range, "West Indies" (Warmke and Abbott, 1961, p. 109).

Coralliophila caribaea Abbott

Coralliophila caribaea Abbott 1958, Acad. Nat. Sci. Philadelphia, Monograph 11, pp. 66, 68.

Three live specimens, largest measuring 15 mm. dredged off McClellanville, S. C. (N. Lat. 32°31.2′; W. Long. 78°51.0′), in 46 meters, on July 3, 1963.

Previous northernmost record, off Palm Beach, Fla. (Abbott, 1958, p. 67).

Hyalina (Volvarina) veliei (Pilsbry)

Marginella veliei Pilsbry 1896, Proc. Acad. Nat. Sci. Philadelphia, *71:* 206.

One medium-sized live specimen dredged off McClellanville, S. C. (N. Lat. 32°31.2′; W. Long. 78°51.0′) in 46 meters, on

July 3, 1963. Two fresh fragments also found in dredgings nearby.

Abbott (1954, p. 258) gave range as west coast of Florida, common in shallow water; Johnson (1934, p. 132) restricted it to Boca Ciega Bay, Fla.

In the specimens we collected the color of the shell is reddish brown on the dorsal surface. In specimens we have seen from shallow water off west Florida, the shell is uniformly yellow. On the other hand, dredged specimens from the deeper waters of west Florida are a uniform white color and are smaller than ones from shallow water.

Pyrgocythara coxi Fargo

Pyrgocythara coxi Fargo, 1953 [in] Pliocene Mollusca of southern Florida, Acad. Nat. Sci. Philadelphia, Monograph No. 8, pt. 2, p. 384, pl. 20, figs. 3, 3a.

Two adult specimens about 8 mm. in length, inhabited by hermit crabs, found in seaweed washed ashore at Ocean Drive Beach, S. C., on Feb. 12, 1960. A third specimen was obtained from a tide pool at Myrtle Beach, S. C., about a year later.

This species was described from the Pliocene of St. Petersburg, Fla., but was also noted at the same time as having been found Recent nearby. Range extensions have appeared twice in the literature in the few years since this small species was described. Abbott (1958, p. 97) reported it from Gun Bay, Grand Cayman Island, B. W. I. and Warmke and Abbott (1961, p. 138) noted its occurrence in Puerto Rico. The occurrence of this species as a Neogene fossil in South Carolina will be reported later.

Sayella crosseana Dall

Sayella crosseana Dall 1885, Proc. U. S. Natl. Mus., 8 (18): 286, pl. 18, fig. 10.

One specimen, 4.3 mm. in length, inhabited by hermit crab, found in seaweed washed on shore at Ocean Drive Beach, S. C., on Feb. 12, 1960.

Previous northernmost record, Matecumbe Key, Fla. (Henderson, 1913, p. 59).

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A NEW SPECIES OF SEAROBIN (TRIGLIDAE)

GEORGE C. MILLER

A PREVIOUSLY unknown species of *Bellator* was recently captured in a bottom trawl by the Bureau of Commercial Fisheries exploratory fishing vessel *Oregon*. This species, a cognate of *Bellator militaris* (Goode and Bean), was taken in the Caribbean Sea and the western Atlantic Ocean off northern South America.

Measurements and counts follow Ginsburg (1950, pp. 490-494) and Miller (in press); names and locations of head spines are from Ginsburg (1953, Fig. 1). Specimens of *B. militaris* from the following stations were used for comparison with the new species: *Silver Bay* 1234, 1341, 1238, 5473, 3656, 2147, 3183, 1558, 1557, 1568, 2629, 2658, 5108, 5106, 5107, 5104, 5105, 2398, 2382; *Combat* 337, 338, 333; and *Oregon* 2838; deposited in the fish collections of the Bureau of Commercial Fisheries Tropical Atlantic Biological Laboratory, Miami, Florida (TABL). In this paper, the terms juveniles or small specimens denote those 35 mm SL and smaller, and adults or large specimens, 75 mm SL and larger.

Harvey R. Bullis, Jr., made these specimens available to me. Frederick H. Berry and Jack W. Gehringer reviewed and edited the manuscript. The illustrations were drawn by Grady W. Reinert.

Bellator ribeiroi, new species

Figs. 1A, 2A, 3A

Holotype: USNM 261273-F1, 93 mm, off São Luis, Brazil, *Oregon* sta. 4238, 2°10′S, 42°24′W, 26 fms., bottom water temp. 84°F, March 11, 1963.

Paratypes: USNM 261273-F3, 3(76-85 mm), *Oregon* sta. 4238, same data as holotype.—USNM 261273-F4, 3(53-58 mm), *Oregon* sta. 4895, 9°35′N, 76°04.5′W, 22-30 fms., May 26, 1964.—USNM 261273-F5, 1(59 mm), *Oregon* sta. 4908, 11°23′N, 73°33.5′W, 25-28 fms., May 31, 1964.—USNM 261273-F6, 1(37 mm), *Oregon* sta. 4875, 10 53′N. 75°22′W, 22-24 fms., May 23, 1964.—USNM 261273-F2, 10(22-50 mm); UMMZ, 3(36-55 mm); TABL, 4(30-51 mm); *Oregon* sta. 4894, 9°32.8′N, 76°09.3′W, 33 fms., May 26, 1964.—BMNH, 3(43-63 mm), *Oregon* sta. 4900, 8 53′N, 76 40′W, 34 fms., May 27, 1964.—MNHN, 2(55, 66 mm), *Oregon* sta. 5031, 11 12′N, 60 35.5′W,

40-42 fms., Sept. 22, 1964.—MN (Brazil), 3(36-42 mm), *Oregon* sta. 4893, 9°33.7′N, 76°05.4′W, 23 fms., May 26, 1964.—MN (Brazil), 1 (69 mm), *Oregon* sta. 4164, 8°00′N, 58°05′W, 30 fms., Feb. 18, 1963. —MCZ, 2(41, 59 mm); ANSP, 2(41, 61 mm); CNHM, 2(46, 62 mm); SU, 2(40, 61 mm); UMML, 2(45, 61 mm); CU, 2(47, 55 mm); TU, 2(53, 59 mm); UW, 3(44-56 mm); *Oregon* sta. 4899, 8°50.5′N, 76° 53.5′W, 37-40 fms., May 27, 1964.—TABL, 4(32-45 mm), *Oregon* sta. 4886, 9°38′N, 75°54.5′W, 23 fms., May 25, 1964.—BLBG, 1(60 mm), Commercial Shrimp Trawler off Surinam, May-Aug., 1962.

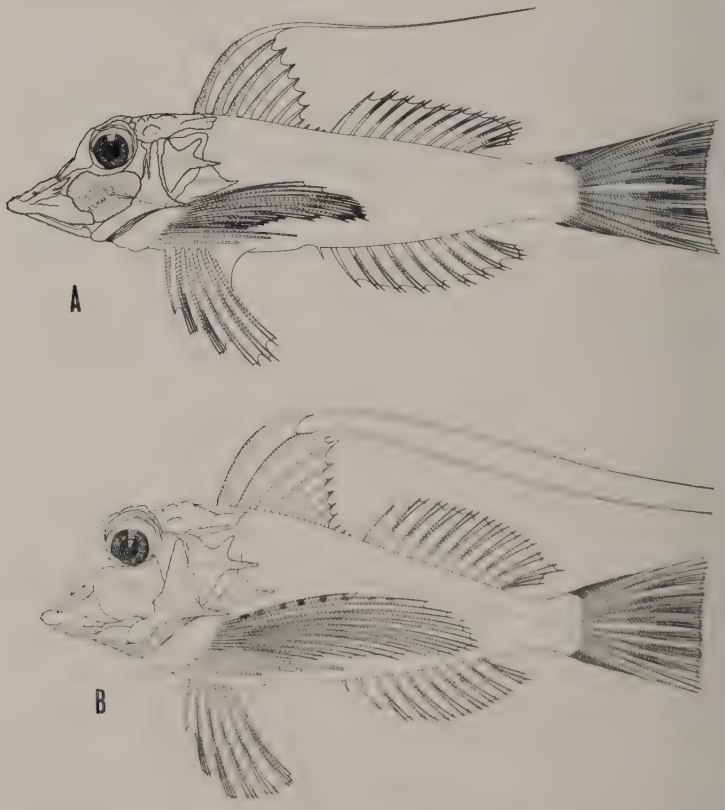

Fig. 1. (A) *Bellator ribeiroi*, holotype, 93 mm SL; (B) *Bellator militaris*, 86 mm SL, *Combat* sta. 337. Lateral view of adults.

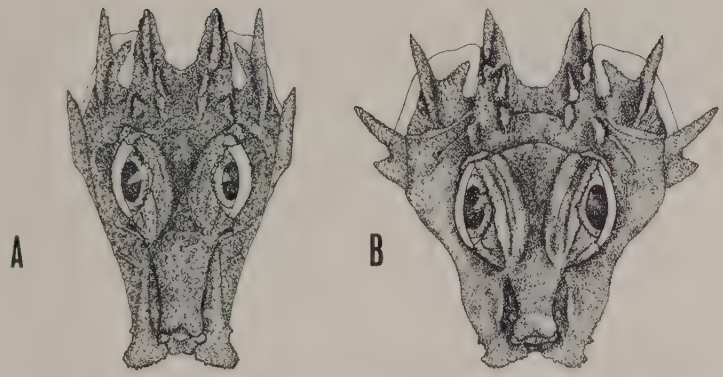

Fig. 2. (A) *Bellator ribeiroi,* holotype, 93 mm SL; (B) *Bellator militaris,* 86 mm SL. Dorsal view of head of adults.

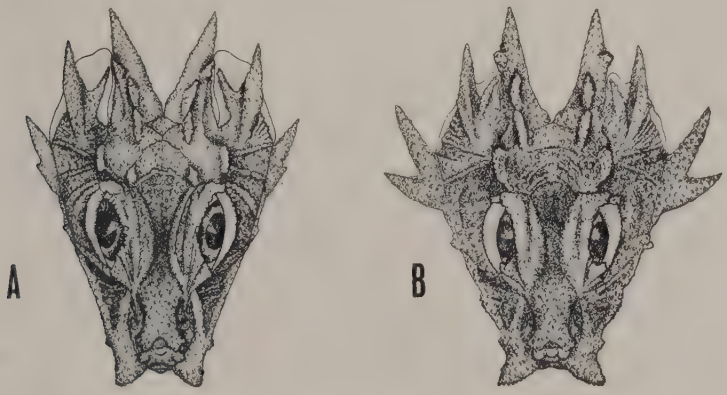

Fig. 3. (A) *Bellator ribeiroi,* paratype, 31.6 mm SL, *Oregon* sta. 4886; (B) *Bellator militaris,* 31 mm SL, *Oregon* sta. 2838. Dorsal view of head of juveniles.

Abbreviations. USNM, United States National Museum. UMMZ, University of Michigan Museum of Zoology. BMNH, British Museum of Natural History. MNHN, Museum National d'Histoire Naturelle. MN(Brazil), Museu Nacional, Rio de Janeiro. MCZ, Museum of Comparative Zoology. ANSP, Academy of Natural Sciences of Philadelphia. CNHM, Chicago Natural History Museum. SU, Stanford University. UMML, University of Miami

Marine Laboratory. TU, Tulane University. UW, University of Washington. BLBG, U. S. Bureau of Commercial Fisheries Biological Laboratory, Brunswick, Ga.

Diagnosis. A *Bellator* with large cleithral spines. Scales present on chest anterior to a line between the median rays of the pelvic fins. Body depth at first dorsal spine slender (Fig. 4), average

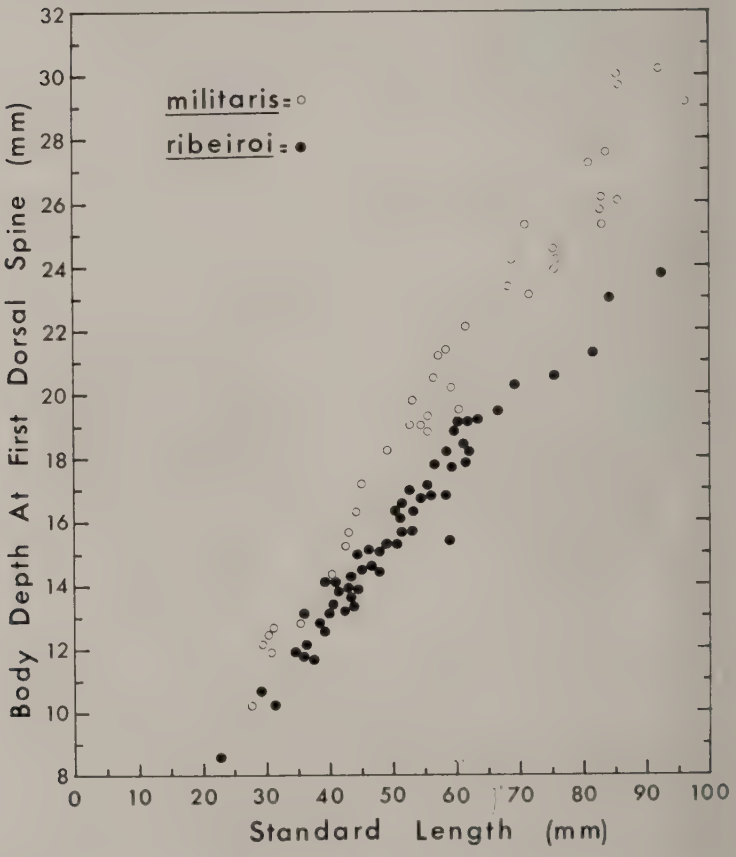

Fig. 4. Comparison of the body depth at the first dorsal spine of 56 type specimens of *Bellator ribeiroi* with 40 specimens of *B. militaris*.

31.6% SL. Interorbital width narrow, average 7.1% SL (Fig. 5). First dorsal spine elongated on many specimens; other dorsal spines never elongated. First (dorsalmost) pectoral ray orange, lacking alternating black and white bands; pectoral fins dusky orange with distal ends of ventralmost branched rays black.

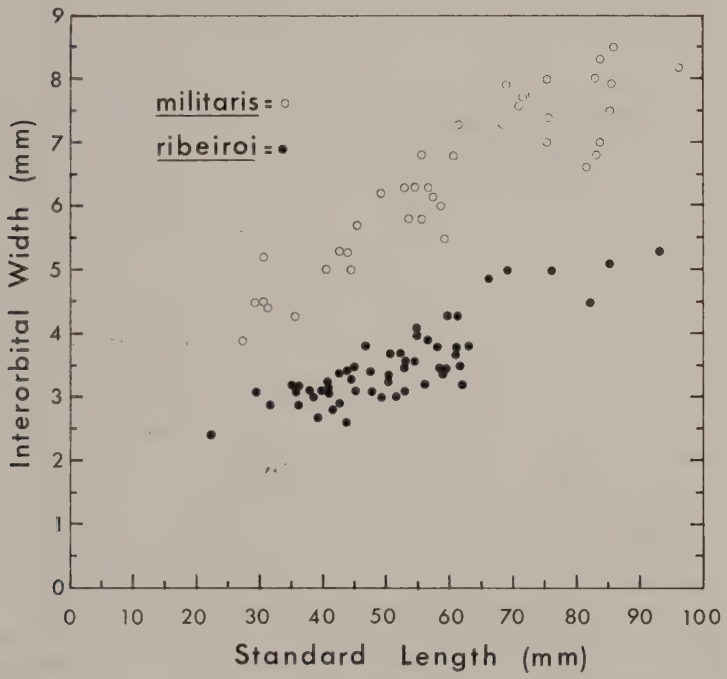

Fig. 5. Comparison of the interorbital widths of 57 type specimens of *Bellator ribeiroi* with 40 specimens of *B. militaris*.

Measurements and Counts. Measurements taken from the 57 type specimens, 22-93 mm SL (average 51 mm SL), were recorded as percentages of standard length (the average followed by the range in parentheses): Head length 43.0 (37.1-51.3); body depth at first dorsal spine 31.6 (26.0-38.4); interorbital width 7.1 (5.2-10.7); least width of rostrum 11.0 (9.1-14.3); pectoral length 45.1 (36.7-55.3); first free pectoral ray length 32.4 (24.2-39.0).

Dorsal spines X-XI, predominately XI. Dorsal softrays 10-11, usually 11. Anal softrays 9-11, usually 10. Pectoral joined rays 11-12, usually 12, plus 3 free rays. Pelvic spine 1. Pelvic softrays 5. Gillrakers and tubercles on first arch usually 17-18; epibranchial, 1 or 2 rakers or tubercles; ceratobranchial, 8 rakers plus 2 tubercles; and hypobranchial, 6 tubercles.

Description. Dorsal spines decreasing in size posteriorly to eighth or ninth spine; posterior two or three spines subequal, small, separate, sometimes scarcely discernible; anterior three spines strongly serrated on anterior edge, fourth and fifth spines bearing some serrations; first dorsal spine elongated on 24 type specimens; short, developing filamentous spine present on specimen 36 mm SL, filamentous spine extending past caudal in a specimen 52 mm SL; second dorsal spine not elongated. First dorsal softray not branched, its anterior edge partially serrated; remaining dorsal softrays branched, last softray divided to its base. Pectoral fin wedge-shaped; middle rays longest, ventral rays decreasing more rapidly in length than dorsal rays; first free ray shorter than longest joined ray; first free ray longer in juveniles (ca. 87% of pectoral length) than in adults (60-80% of pectoral length). Membrane connecting median pelvic ray to side of body. Caudal fin emarginate. Membrane of mouth attached to epibranchial bone of first gill arch, extending nearly to articulation of epibranchial with ceratobranchial; tubercles on hypobranchial bone not fused. Scales absent on abdomen from line between median rays of pelvics posteriorly for one-half the distance to the anus.

Supraocular and postocular spines large in juveniles, becoming small to obsolete in adults. Frontal spine small, located in occipital groove, decreasing in relative size with growth of fish. Anterior parietal spine smaller than prominent posterior parietal spine in small specimens, the spines reduced to rounded ridges in large specimens. Upper posttemporal spine large, a smaller lower posttemporal spine in small specimens decreasing to a low flat ridge in large specimens. Pterotic ridge elevated, with blunt edge. Opercular spine long. Preopercular spine not extending to tip of opercular spine; supplemental preopercular spine small in small specimens, becoming obsolete in large specimens. Rostral exsertions short, either rounded or triangular, usually terminating anteriorly as one or more small spines. Single, small preorbital (lachrymal) spine on edge of rostrum near base of exsertion. Low ridge extending an-

teriorly from supplemental preopercular spine, terminating as a spine beneath center of orbit in small specimens; in large specimens ridge present, but spine absent or vestigial. Nasal and preocular spines absent. Occipital groove deep. Cleithral spine long, extending posteriorly past distal ends of opercular and preopercular spines. Head proportionately longer in small specimens, 20-30 mm SL (48-51% SL), than in large specimens, 75-95 mm SL (37-43% SL). Interorbital width very narrow (Fig. 5). Body depth at first dorsal spine slender in comparison to *B. militaris* (Figs. 1, 4).

Coloration of specimens preserved in solution of 10 per cent formalin and IONOL CP-40: Body orange; ventral edge of pectoral fin and tips of branched rays dark; pectoral dusky orange with first (dorsalmost) ray not banded with black and white. Pigmentation: Large black spot near edge of membrane between fourth and fifth dorsal spines, usually absent in specimens larger than 60 mm SL; distal ends of branched rays on lower edge of pectoral fin dark; dark spot at base of last dorsal soft ray. There are indications that *Bellator ribeiroi* has spawning colors as brilliant as those reported for *B. militaris* by Longley and Hildebrand (1941, p. 174).

Common Name. Ribeiro's Searobin.

Etymology. This species is named in honor of the Brazilian ichthyologist, Alipio de Miranda Ribeiro, who contributed greatly to the knowledge of the marine fauna of South America.

Range. The range of *B. ribeiroi* is known to extend from Colombia to Brazil. It has been taken at depths ranging from 22 to 42 fathoms, in bottom water temperatures of 74° to 84°F. (records for 3 stations only).

The closely associated cognate, *B. militaris*, ranges from Cape Lookout, North Carolina, south in the western Atlantic through the Gulf of Mexico to off Cabo Catoche, Yucatan, Mexico (Ginsburg, 1950, p. 527). It is not known whether *B. ribeiroi* and *B. militaris* occur sympatrically off Central America, between Colombia and Yucatan, or are absent from this area. The largest specimens of *B. ribeiroi*, like *B. militaris* (Ginsburg, 1950, p. 527), are from the most southern part of its known range.

Species. The genus *Bellator* is endemic to the western Atlantic Ocean, and is now known to include four species. *Bellator ribeiroi* may be distinguished from the other three species by the following key.

I. Cleithral spine large, extending posteriorly past tip of opercular spine; scales present on chest anterior to a line between the median rays of the pelvic fins.

A. Upper (dorsalmost) one or two rays of pectoral banded black and white; supplemental preopercular spine usually large; interorbital broad, average 11.8% SL; first and second dorsal spines elongated in many specimens (neither spine elongated in others)..... *Bellator militaris* (Goode and Bean)

AA. Upper rays of pectoral lacking black and white bands; supplemental preopercular spine small or absent; interorbital area narrow, average 7.1% SL; only first dorsal spine elongated in many specimens (no elongated spine in others) *Bellator ribeiroi*, new species

II. Cleithral spine small, not extending past tip of opercular spine; lacking scales on chest.

B. Posterior upper portion of eyeball with tabs or tentacles; first free ray of pectoral much shorter than pectoral length; outer face of pectoral with alternating patches of light and dark color ..... *Bellator egretta* (Goode and Bean)

BB. Posterior upper portion of eyeball without tabs or tentacles; first free ray of pectoral considerable longer than pectoral length; outer face of pectoral dusky or with an elongated black spot ..... *Bellator brachychir* (Regan)

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(Reprinted from Research Briefs, Fish Commission of Oregon, Volume 11, Number 1, June, 1965.)

Western North American Crawfishes (Pacifastacus) In Brackish Water Environments[1]

GEORGE C. MILLER[2]

INTRODUCTION

During a study of the western North American fresh-water crawfishes, some specimens of *Pacifastacus leniusculus* (Dana) and *Pacifastacus trowbridgii* (Stimpson) were found in brackish water. The purpose of this paper is to review literature reporting fresh-water crawfishes in brackish areas, list brackish areas in the western United States where *Pacifastacus* species are found, substantiate migration of crawfishes from brackish to fresh water in the lower Columbia River, present observations on crawfishes in brackish water, and list the fauna associated with crawfishes in a tributary of the Columbia River estuary.

REVIEW OF LITERATURE

Three species of the European fresh-water crawfish, genus *Astacus*, occur in brackish water. Huxley (1880) reported that *Astacus astacus* (Linnaeus), under the name of *Astacus nobilis* (Schrank), "is said occasionally to be met with on the Livonian coast in the waters of the Baltic, which, however, it must be remembered are much less salt than ordinary sea water"; *A. leptodactylus* Eschscholtz, "not only thrives in the brackish waters of the estuaries of the rivers which debouche into the Black Sea and the Sea of Azov, but that it is found even in the salter parts of the Caspian in which it lives at considerable depths"; and *A. pachypus* Rathke, "In the Caspian and in the brackish waters of the estuaries of the Dniester and the Bug, a somewhat different crayfish, which has been called *Astacus pachypus* occurs."

Western North American crawfish have been reported from brackish waters in Washington and California. Cooper (1860) found *P. trowbridgii* in streams running into Shoalwater Bay (now called Willapa Bay), Washington, and stated, "It sometimes gets into the brackish water of the bay, but probably returns to the fresh streams as soon as possible." Collins (1892) reported lobsters in Monterey Bay, California, during the rainy season, but Smith (1896) noted that such specimens captured during the summer were identified by Professor Charles H. Gilbert as fresh-water crawfish. Faxon (1898) identified a form intermediate between *P. leniusculus* and *P. trowbridgii* as *P. trowbridgii* and added that "this large female had been taken from a bunch of seaweed in salt water at Monterey, California." Riegel (1959) noted that on one occasion *P. leniusculus* was collected in California in dilute brackish water.

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[1] Contribution No. 74, U. S. Bureau of Commercial Fisheries Biological Laboratory, Brunswich, Georgia. Based upon portions of a thesis accepted by the Graduate School, Oregon State University, 1960, in partial fulfillment of the requirements for the degree of Master of Science.

[2] Formerly biologist, Oregon Fish Commission; now Fishery Biologist (Research), U. S. Bureau of Commercial Fisheries Biological Laboratory, Brunswick, Georgia.

Four species of the eastern North American crawfish are known to occur in brackish environments. Penn (1943) reported that *Procambarus clarkii* (Girard) "extends even down to the coastal marshes, if they are not more than slightly brackish." In another study Penn (1956) said that "A number of collections of *P. clarkii* have been made in slightly brackish marshes and along the shores of Lake Pontchartrain where salinity ranged as high as $6^0/_{00}$. In this connection it is worth noting that Helff (1929, 1931) using mature specimens and Steeg (1942) using juveniles demonstrated that *P. clarkii* can survive laboratory tests for a week in 1.17 and 1.5 per cent solutions (11.7 and $15.0^0/_{00}$) of NaCl respectively, but are killed in significant numbers by stronger NaCl solutions."

In referring to *Procambarus pycnogonopodus* Hobbs in Florida, Hobbs (1942) said that "In Walton County, about 16 miles east of Niceville, a small stream from a flatwoods pond flows into the bay. Here several specimens of *pycnogonopodus* were taken from the stream proper, and one was taken about 50 yards from the mouth of this stream in Choctawhatchee Bay, where the water is definitely brackish. Several clear streams also flow into the bay from its northern shore in Walton County. In several of these *pycnogonopodus* was collected within 15 yards of the bay."

Referring to *Cambarus uhleri* Faxon, Faxon (1884) remarked, "It is found in salt marshes, covered twice daily by the tides, and also in brackish and fresh-water ditches in company with *C. blandingii*."

The Asiatic crawfish, *Cambaroides schrenckii* Kessler, also may occur in brackish water since this species and the brackish water crustaceans, *Crangon septemspinosa* Say, *Mesidotea entomon orientalis* Gurianova, and *Pagurus capillatus* Benedict, were all found in the stomach contents of white whales by Tomilin (1957).

OCCURRENCE OF P. trowbridgii AND P. leniusculus IN BRACKISH AREAS

The localities where crawfishes were captured in brackish water in Oregon and Washington are given in Table 1, and the localities in the Columbia River estuary are shown in Figure 1.

MIGRATION BETWEEN BRACKISH AND FRESH WATER

Upstream and downstream migrations of crawfish occur in some of the streams entering brackish water in Oregon and Washington. Henry (1951) reported a downstream movement of *P. klamathensis* (Stimpson) in the spring and an upstream migration in the fall in Spring Creek, a tributary of the coastal Wilson River in Oregon. All the crawfish collected in Spring Creek were *P. trowbridgii*, as confirmed by Dr. James Lynch of the University of Washington.

Dr. Ernest Salo of Humboldt State College, and R. E. Noble of Washington State Department of Fisheries (in litt.) reported a definite downstream movement of crawfish in the spring at the Minter Creek weir in Washington. Other members of the Washington Department (in litt.)

TABLE 1. **LOCALITIES WHERE CRAWFISH WERE CAPTURED IN OREGON AND WASHINGTON IN BRACKISH WATER.**

Species	*Locality*	*County*	*State*
Pacifastacus trowbridgii	Columbia estuary, at Megler and Fort Columbia	Pacific	Wash.
"	Columbia estuary, beneath docks at Astoria	Clatsop	Oregon
"	Skipanon River, under U. S. Highway 101 bridge	"	"
"	Youngs River, immediately upstream from U. S. Highway 101 bridge	"	"
"	Creek, entering Youngs River at the Astoria garbage dump	"	"
"	Walluski River, beneath Oregon State Highway 202 bridge	"	"
"	Alder Creek, under highway bridge between towns of Warrenton and Hammond	"	"
"	Necanicum River at Seaside	"	"
"	Siuslaw River, in tidal pool 1 mile above U. S. Highway 101 bridge	Lane	"
"	Chinook River, at Prest Farm	Pacific	Wash.
"	Wallicut River, under U. S. Highway 101 bridge	"	"
"	Bear River, at lime quarry	"	"
"	Naselle (Nasel) River, immediately above town of Naselle	"	"
"	Middle Nemah River, under U. S. Highway 101 bridge	"	"
"	Deep River, at Peters-McKinnon log dump	"	"
Pacifastacus leniusculus	Columbia estuary, beneath docks at Astoria	Clatsop	Oregon
"	John Day River, beneath U. S. Highway 30 bridge	"	"
"	Deep River at Peters-McKinnon log dump	Pacific	Wash.

stated that crawfish move downstream through the weir at North Nemah River hatchery in spring and early summer. Dr. Donald Chapman found (in litt.) that crawfish move downstream in the spring through a weir in a tributary of the Alsea River in Oregon. All the specimens I examined from Minter Creek, Alsea River, and North Nemah River were *P. trowbridgii*.

Many small creeks and streams where *P. trowbridgii* is found flow into the Columbia River estuary. Because there are no weirs near the mouths of these streams, it cannot be determined if a downstream movement occurs in the spring. It may be only surmised that the crawfish from these tributaries have the same general migration pattern as those cited for this species in coastal areas.

Within a short period of time, crawfish definitely migrate in the fall from the brackish Columbia estuary into fresh-water creeks and rivers. Whether this migration includes the total population in the estuary or only a part is not known. The migration is well known to many people of the Astoria region who engage in a sport fishery for the crustaceans along the shore (also reported to me by Dr. George Y. Harry, Jr., Edwin Niska, and Eldon Korpela of the Oregon Fish Commission in Astoria, and Russell Sinnhuber and Duncan Law of Oregon State University).

In early November 1957, personnel at the Columbia River Packers Association's Elmore Cannery on the Columbia River at Astoria (Figure 1) were seen lifting traps loaded with barnacled crawfish. One of the workers

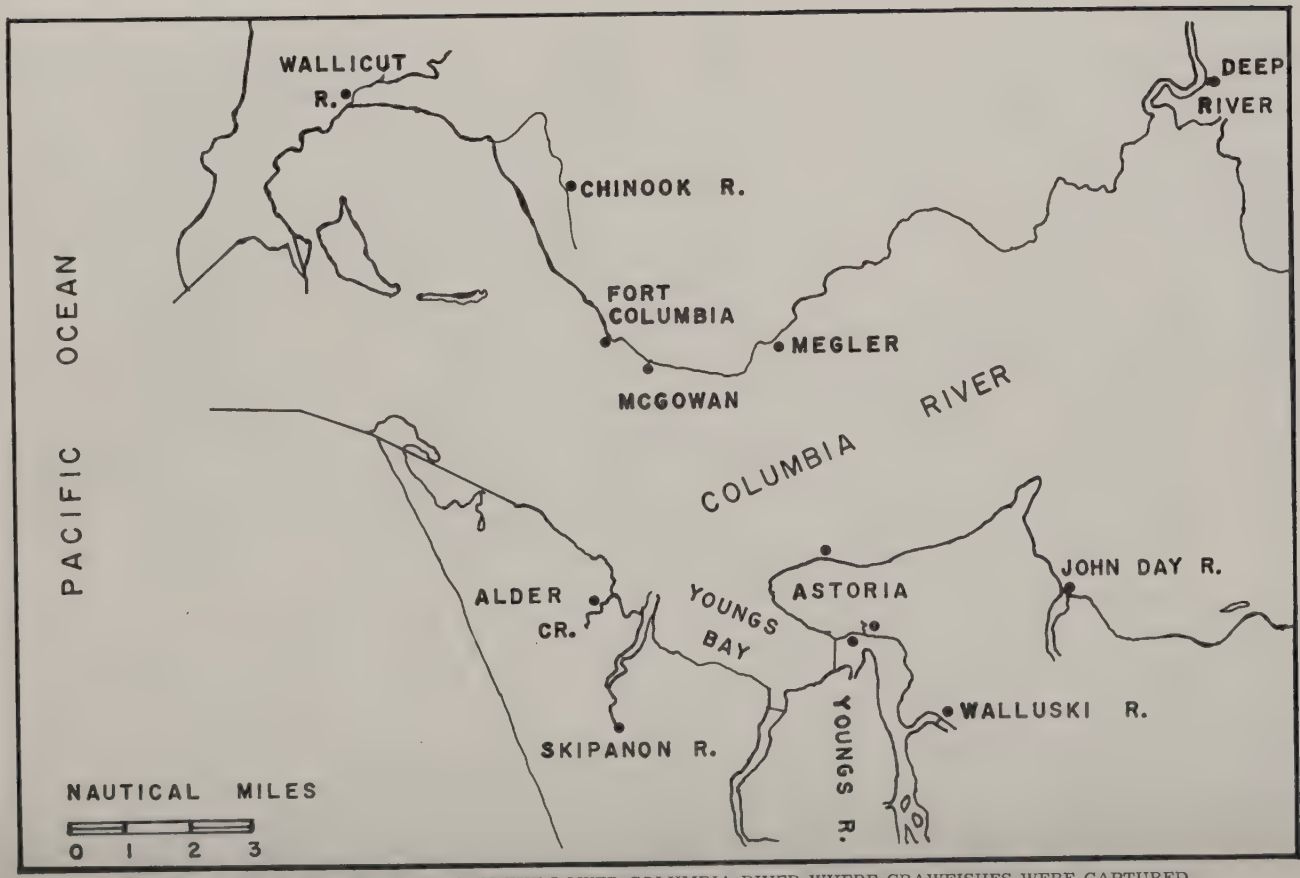

FIGURE 1. BRACKISH WATER AREAS IN THE LOWER COLUMBIA RIVER WHERE CRAWFISHES WERE CAPTURED.

reported that his son had captured a large number the previous night along the eastern Astoria waterfront near Tongue Point. If crawfish inhabited the area beneath this cannery in September, they occurred in salinities ranging between 15 and 20$^{0}/_{00}$ (Burt and McAlister, 1959).

Traps set beneath the Elmore Cannery and the C.R.P.A. shipyard on Youngs River, Astoria, in early November 1957, caught crawfish partially covered with large live barnacles, *Balanus improvisus* Darwin, as seen in Figure 2 (the water is brackish in both localities). A week later, David Leith, biologist of the Oregon Fish Commission, found crawfish encrusted with live barnacles crawling out on the banks of a fresh-water tributary more than a half mile upstream from its confluence with Youngs River. Frank Parker, a local fisherman, reported (in litt.) he had taken a large number of barnacle-encrusted crawfish from this same creek for eating, but was forced to discard them because they were contaminated with oil. The following April, crawfish captured in traps in the brackish portion of the Walluski River were found bearing the outer plates of dead barnacles on their carapaces. These crawfish had probably wintered in the fresh-water stretches of the river.

Eldon Korpela (in litt.) stated he had seen in the fall numbers of crawfish congregating at low tide in shallow water beneath sewer or rain-overflow pipes on the Astoria waterfront. This observation may suggest that the fall migration is not a return to a parental stream, but random movement into any source of fresh water.

REPRODUCTION AND GROWTH IN BRACKISH WATER

Moulting of *P. trowbridgii* does not appear to be affected by the brackish condition of the water. Some crawfish caught in brackish Youngs River at Astoria in November 1957 had new, light-brown, post-moult exoskeletons, while others had old, black, barnacle-encrusted exoskeletons. Females in this sample had small to large barnacles on the body and were bearing fertile black eggs. It appears that copulation had taken place in brackish rather than fresh water since copulation and egg laying do not occur in this species until late September or October.

A young *P. trowbridgii* in the act of moulting was observed stranded on a bank left by the receding tide below a lime quarry on Bear River, Washington, on July 25, 1959. Exposed to the sun and in a weakened condition it was unable to complete the moult. After being returned to the river it quickly revived, shed the old exoskeleton, and made itself inconspicuous under nearby debris on the bottom.

In May adults (which included ovigerous females) and juveniles of *P. trowbridgii* were found in the Columbia estuary at Megler. During June and July, the recently dropped young, approximately 11 millimeters long, were seen hiding beneath small rocks high in the intertidal zone.

OBSERVATIONS ON P. leniusculus IN DEEP RIVER

The life history of *P. leniusculus* was studied in the tidal portion of Deep River, Washington. Bottom temperatures and water samples for salinity determinations were taken every 35 days or less from December

FIGURE 2. DORSAL, LATERAL, AND VENTRAL VIEWS OF A FEMALE *Pacifastacus trowbridgii* WITH THE BARNACLE *Balanus improvisus* ON BODY.

1955 to November 1957, in about 20 feet of water at the Peters-McKinnon log dump. Salinities were measured by a standard hydrometer. Only the data pertinent to this report are given here.

During the investigation salinity was unusually high in Deep River, ranging from $12.8^0/_{00}$ to $13.7^0/_{00}$ between May 19 and July 29, 1956. During a comparable period in 1957 the salinities in the same area ranged from $0.2^0/_{00}$ to $0.6^0/_{00}$, comparable to those reported by Burt and McAlister (1959) in their study of the Columbia River estuary.

The trap catch, reproduction, and growth of *P. leniusculus* in Deep River, when compared with that of populations found in other areas, did not appear to be affected by the high salinity in Deep River in 1956. During the period from May 19 to September 30, 1956, when the bottom water temperatures were warm, varying between 16 to 22 C., crawfish were actively entering the traps and feeding. Seven trap samples taken between June 15 and September 30 yielded 2,702 specimens, an average of 386 per sample. In both *P. leniusculus* and *P. trowbridgii* increasing feeding activity, as evidenced by increasing trap catch, can be correlated with rising bottom water temperatures in spring and summer, while the converse is true in the fall and winter.

Andrew's (1907) speculation that female *P. leniusculus* become ovigerous in October agrees with my findings for the population of this species in Deep River. A sample from Deep River, taken on September 30, 1956, yielded no ovigerous females but such females occurred in the sample taken on November 3. Six samples taken from Deep River between November 3, 1956 and March 22, 1957 produced 182 females, of which 75 were ovigerous.

Moulting is indicative of growth in crawfish. The criteria used for determining the time of moulting in Deep River were based on texture and coloration of the carapace and chelipeds. All specimens that had undergone a recent moult were light brown in color and tinged blue ventrally, whereas those that had not moulted recently were dark brown to black and lacked the blue ventral tinge. Recently moulted crawfish were classified in three categories: (1) soft, those in which the carapace was still soft and spongy; (2) semi-hard, those in an early post-moult condition in which the carapace had hardened on the dorsal surface but was still semi-soft laterally; and (3) hard, those in a late post-moult condition with the carapace completely hardened but distinguishable by the light brown exoskeleton tinged with blue. Lateral pressure on the sides of the carapace of a semi-hard crawfish would cause an indentation which disappeared after the pressure was released. The crawfish catch in Deep River on July 29, 1956 consisted of 7 males and 11 females in a soft condition, 2 males and 9 females in a semi-hard condition, and 6 males and 11 females in a hard condition.

FAUNA ASSOCIATED WITH CRAWFISH IN YOUNGS RIVER

The barnacles on the crawfish in the estuary were identified by Dr. William Newman of the University of California as *Balanus improvisus*. Dr. Ralph Smith, also of the University of California, noted (in litt.) that

this species is not an indicator of any particular salinity although it suggests that the water was not quite fresh.

The fishes captured with *P. trowbridgii* in traps and trawls in Youngs River are commonly found in estuarine environments with the exception of the longfin smelt which is catadromous. They included Pacific staghorn sculpin, *Leptocottus armatus* (Girard); prickly sculpin, *Cottus asper* Richardson; shiner perch, *Cymatogaster aggregata* Gibbons; starry flounder, *Platichthys stellatus* (Pallas); juvenile English sole, *Parophrys vetulus* Girard; and longfin smelt *Spirinchus dilatus* Schultz and Chapman. In reporting on *Cottus asper*, McAllister and Lindsey (1960) noted that "its wide range may be attributed in part to its tolerance of brackish water."

ACKNOWLEDGMENTS

Thanks are due to Howard McKinnon for the use of his boating facilities and wharves at Deep River, Washington; Clyde Sayce of the Washington Department of Fisheries for his assistance with salinity determinations and cooperation on the Deep River study; and Dr. William Newman and Dr. Ralph Smith for identifying and providing information on *Balanus improvisus*. Some members and associates of the Oregon Fish Commission research staff cooperated in the study. Dr. Horton H. Hobbs, Jr., U. S. National Museum, reviewed the manuscript and gave helpful suggestions and criticisms.

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CONSEIL PERMANENT INTERNATIONAL POUR
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RAPPORTS ET PROCÈS VERBAUX, VOL. 156, 1965

9.

Preliminary Report of the Effect of Varying Levels of Fishing on Eastern Bering Sea King Crabs, *Paralithodes camtschatica* (Tilesius)

By

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Introduction

This paper is a review of our initial effort toward assessing the effects of fishing upon the population and catch of eastern Bering Sea king crabs, *Paralithodes camtschatica*. In this preliminary review, details of the study are only generally reported and methods are emphasized.

The king crabs are anomurans of the family Lithodidae and are found in the North Pacific Ocean, the Bering Sea, and the Okhotsk Sea. Two other species, *P. platypus* and *P. brevipes*, are known to occur in the eastern Bering Sea, but as they are found infrequently, our discussions will concern only *P. camtschatica*.

Background

Commercial operations on king crabs in the eastern Bering Sea were initiated by Japanese fishermen in 1930. With a factory-mothership and a fleet of 11 vessels fishing with tangle nets, the operation in that year captured and processed approximately one million crabs. During the three years from 1932 through 1934, Japanese fishermen took 1·2, 2·1 and 1·3 million crabs, respectively. In the ensuing five years, the level of fishing effort was reduced, and the yield ranged from 0·2 to 0·5 million crabs each year. There were no commercial operations in the area from 1940 through 1946.

King crab fishing by United States otter trawlers in the eastern Bering Sea began in 1947. The catch in that year was 0·1 million male crabs. In succeeding years through 1952, U.S. catch varied from 0·2 to 0·5 million per year.

The Japanese re-entered the eastern Bering Sea king crab fishery in 1953 and caught 1·3 million male crabs which, combined with the U.S. catch in the same year, totalled 1·6 million crabs. As shown in Figure 1, the Japanese catch remained relatively constant each year until 1960, while United States catches have been negligible since 1957. Since 1959, the Soviet Union has also engaged in the eastern Bering Sea king crab fisheries. Although not shown in Figure 1, the combined catch by Japanese and Russian fleets in 1961 is estimated to have exceeded 5 million crabs, of which Japan took about 3 million.

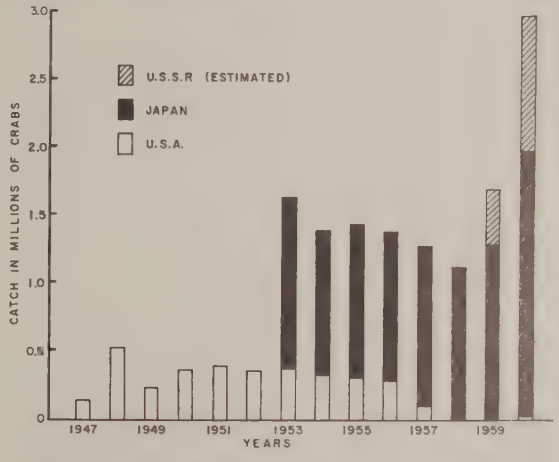

Figure 1. Eastern Bering Sea catch of male king crabs, 1947 through 1960.

King crab investigations by the Bureau of Commercial Fisheries began in 1953, and in 1954 were included as a part of the research programme of the International North Pacific Fisheries Commission, of which Canada, Japan and the United States are members. In 1953, data were collected aboard a Japanese

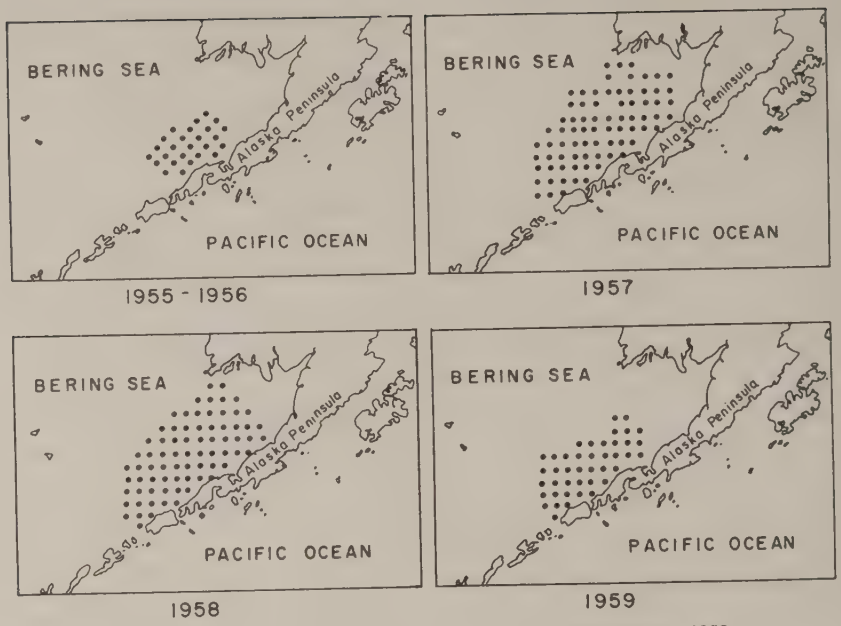

Figure 2. King crab sampling stations for the years 1955 through 1959.

factory-mothership, and in 1954 observations were made from a United States factory otter trawler. In subsequent years, our investigations were intensified, and a United States otter trawler was chartered each year to fish at a series of stations spaced at 20 mile intervals. Figure 2 shows the stations fished in the years from 1955 through 1959. Activities at sea were primarily directed toward collecting data on crab distribution, abundance, size and sex compositions, and moulting rates. Tagged crabs were released to gain information on migrations, growth, and mortalities.

Our knowledge of the species and the fisheries has been increasing steadily. An important problem has been that of moulting in the male king crab. Small crabs may moult several times during a year, but as they approach sexual maturity at a size of about 85 to 90 mm in carapace length, moulting frequency decreases to no more than once annually. Mature female king crabs continue to moult annually, but as the males continue to grow, they appear to moult biennually or even less frequently. VINOGRADOV (1945), in his study of Okhotsk Sea king crabs, reports that the majority of large males moult once every two years. Our records show that several tagged eastern Bering Sea crabs have been returned after three years with no evidence of having moulted during the interval.

In the eastern Bering Sea, male moult appears to occur in the late winter and early spring. Since both the quality and the quantity of meat from non-moulting crabs is superior to that of those which have recently moulted, the summer fisheries are selective for non-moulters. The fisheries are also selective for males because they are relatively larger than females, and most particularly sought after are the larger males.

The method used here to estimate the effects of this selective fishery is to take an arbitrary number of crabs at a size when they become generally available and subject them to parameters of growth, fishing mortality, and natural mortality. The results will show some of the effects that various levels of fishing might be expected to have upon the eastern Bering Sea king crab stock, and the associated changes in the nature of the commercial catch.

Assumptions and qualifications

In analyses of this type where parameters of growth, fishing and natural mortality rates are combined in a yield per recruit model, it is necessary to make certain assumptions and qualifications. These conditions are as follows: –

1. The stock which is under consideration will consist of all eastern Bering Sea male king crabs with carapace lengths 133 mm and greater.

A definition of the stock is essential to the discussion. In choosing this particular definition, we were guided by the fact that although our sampling of immature crabs has not been adequate, male crabs of 133 mm and greater are well represented in our sampling. Our analyses are based on sampling programmes conducted in 1957 and 1958 which were designed to sample the entire adult male population.

2. For convenience in discussions, the year has been divided into two six-month periods called winter and summer. Winter is from November through April, and summer is from May through October.

3. Recruitment is regarded as instantaneous and occurs between the end of winter and the beginning of summer.

Since our surveys covered the entire distribution of the stock, recruitment occurring from immigration is considered to be negligible. Recruitment from growth can be considered instantaneous since moulting and therefore growth occurs during the winter period and is completed by the time fishing commences in the summer.

4. To simplify the analysis the only fishing considered during 1957 and 1958 is that of the single Japanese mothership that operated in the area.

During 1957, the Japanese factory-mothership, "Tokei Maru" caught 92% of all crabs taken in the eastern Bering Sea. In 1958 she caught 100%.

5. During the summer period the stock is affected only by fishing, and crabs neither grow nor die from natural causes.

For the period of years considered in the analyses, the fisheries began in late April and terminated in late June or early July. There was little or no fishing in the area at any other time of the year. We assume that the large, male king crabs included in this study do not grow during the summer period because their moulting occurs only during the winter period. The assumption that natural mortality does not affect the stock during the summer period is based on the supposition that deaths from causes other than fishing are probably greatest during and immediately after moult. Although some crabs undoubtedly die during the summer, these deaths are probably minor in comparison to those that occur during the period of moulting.

6. The numerical size of the stock, the stock size composition, and the rates of growth, natural mortality and recruitment were stabilized during the 1957–1958 period for the level of fishing intensity which occurred during the 1953–1958 interim.

We have no evidence to support this assumption. In fact, evidence of variations in year-class strength and short-term changes in size compositions has been recorded. We suspect, however, that these are normal variations which do not invalidate the assumption. There is evidence of a very low fishing rate during the period from 1953–1958 which was preceded by a 14-year interval of considerably less fishing. The changes in the natural parameters of this stock brought about by fishing would appear, therefore, to be slight.

7. In estimating the effects that increased fishing will have upon the crab stock and its yield, we assume first that there will be no change in the rates of growth, natural mortality, or recruitment, and second, that size selection of the fishing gear will remain essentially similar to that observed in 1957–1958.

Method of analysis

Estimates of three population parameters – growth, fishing mortality, and natural mortality – were used to develop a yield-per-recruit model.

Determination of the king crab growth rate is complicated by the fact that records of growth such as the scales or otoliths in fish are not present. Increase in size occurs only when the animal moults, and the intermoult periods are characterized by constant size. In addition, the growth increment and the interval between moults are quite variable.

Weber and Miyahara (1962) have described two methods used to estimate the growth of adult male king crabs in the eastern Bering Sea. Determination of growth for the smaller sizes is based upon modal progressions in size frequency distributions taken over a five year period from 1955 through 1959. In the larger sizes, year-classes tend to overlap due to non-moulting crabs, and modes are probably made up of various year-classes. The growth of these latter crabs was determined by weighting the growth increment per moult of tagged crabs by the proportions of each size observed to moult.

The growth rates calculated in each year from 1956 through 1959 are shown in Figure 3. The low growth rate for 1957 is attributed to an unexplainable low proportion of moulting crabs in that year. The rates based on 1956, 1958, and 1959 are in close agreement, and we shall use the 1958 rate in the discussions which follow.

The second parameter to be considered is that of fishing mortality. The method used to assess the rates at which the various sizes of crabs are taken is based on catch data furnished by the Japan Fisheries Agency and compared with abundance estimates of the eastern Bering Sea king crab population developed from trawl survey catches.

The trawl surveys upon which our abundance estimates are based consisted of otter trawling over the pattern of fishing stations located at 20 mile intervals. In attempting to sample the entire population, in 1957 and 1958 our patterns were extended outwardly

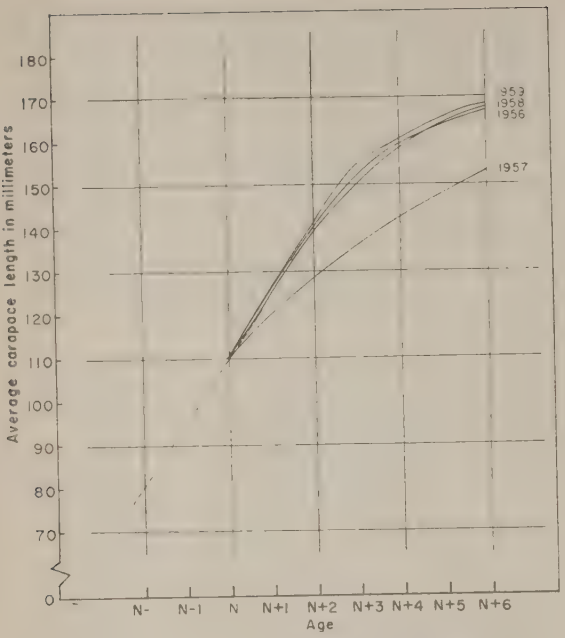

Figure 3. The average growth rates of the adult male king crabs as calculated from data for 1956 through 1959. The dotted line was determined from progressions of modes in size frequency distributions and the solid line from a method incorporating growth per moult weighted by the proportion of moulting crabs observed in each year. Taken from WEBER and MIYAHARA, 1962.

in all directions until few or no crabs were caught. During each tow in 1957 and 1958, data on trawl door spread and distance towed were collected in order to compute the area covered by the trawl. The area covered was used with the numbers caught to estimate the average density per unit area. Expanding the density per unit area for each station by the total areas represented by the stations pattern provided us with estimates of the numbers of crabs in the population. Inherent in this method is the assumption that all crabs in the trawl's path were caught. If this is not so, then their abundance would be underestimated, which would be an error in the preferred direction.

Since the surveys were conducted after the fisheries had terminated for the year, or as in the case of the first survey of 1958, was conducted during the fishing season, the estimated abundances were increased by the commercial catches made prior to the survey. The percentage of each 5 mm size class taken by the fishery was then calculated by comparing catch data supplied by the Japan Fisheries Agency against the estimated abundance of each size. The mean percentages taken by the 1957 and 1958 fisheries are plotted in Figure 4. The line is fitted by inspection.

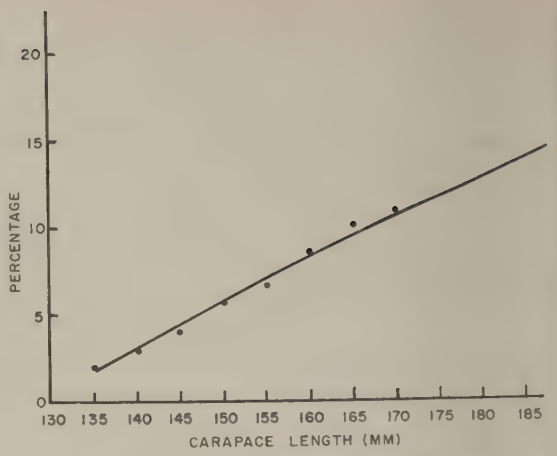

Figure 4. Mean percentage of estimated abundance taken by the eastern Bering Sea king crab fishery.

If the 135 mm size group is considered to have been recruited in year 1, it can be expected on the average to grow in subsequent years to the sizes shown in Table 1 (column 2). The percentage of each age-group taken by the fisheries is also indicated (column 3).

Table 1.

Average sizes and percentages fished by years after recruitment

Year	Carapace length (mm)	Crabs fished (%)
1	135	1·8
2	146	5·0
3	156	7·3
4	162	9·1
5	167	10·3
6	170	11·1
7	173	11·8
8	176	12·1
9	179	13·1
10	182	13·9
11	185	14·8

The report on growth of king crabs by WEBER and MIYAHARA (1962) carries average growth only to 167 mm. The extension included in Table 1 is an extrapolation based on an average annual increment of 3 mm.

The third parameter, natural mortality, was determined from tagging experiments. The declining rates of tag returns were used to calculate survival rates and total annual mortality. Fishing mortality was then subtracted from the mean total annual mortality to provide an estimate of natural mortality.

In the analysis of tag recovery data, it was necessary to account for factors that influenced year to year

Table 2.
Yield-per-recruit model for 1957-1958 level of fishing
(Survival rate=0·48)

Year	Season	Population number at start	Fishing mortality (%)	Numbers caught	Natural mortality (%)	Numbers natural deaths	Average carapace length (mm)	Average live weight* (kg)	Yield (kg)
1	Summer	10,000	01·8	180			135	2·05	369
	Winter	9,820			51·1	5,020			
2	Summer	4,800	05·0	240			146	2·60	624
	Winter	4,560			49·5	2,256			
3	Summer	2,304	07·3	168			156	3·35	563
	Winter	2,136			48·2	1,030			
4	Summer	1,106	09·1	101			162	3·60	364
	Winter	1,005			47·2	474			
5	Summer	531	10·3	55			167	3·95	217
	Winter	476			46·4	221			
6	Summer	255	11·0	28			170	4·15	116
	Winter	227			46·2	105			
7	Summer	122	11·7	14			173	4·30	60
	Winter	108			46·3	50			
8	Summer	58	12·3	7			176	4·50	32
	Winter	51			45·1	23			
9	Summer	28	13·0	4			179	4·75	19
	Winter	24			45·8	11			
10	Summer	13	13·5	2			182	4·90	10
	Winter	11			45·4	5			
11	Summer	6	14·1	1			185	5·05	5
	Winter	5			40·0	2			

*Live weights are from length-weight data collected during the study.

variations in recovery. Since it is doubtful that all tagged crabs were equally available to the fishery during the period when tags were being released, only tagged crabs recovered after at least one winter at sea were considered in the calculation of survival rates. Variation in fishing intensity was accounted for by weighting recoveries to a common measure of intensity based on catch. Although measures of effort are more commonly used, we used catch since there appear to be increasing fishing efficiency and also variation in scouting effort between years which cause us to doubt the reliability of available measures of fishing effort.

The selectivity of the fishery for the larger and non-moulting male crabs may also cause variability in tag returns in successive years. Since small crabs moult more frequently than the large, the likelihood of recovering small tagged crabs is low. However, as they grow to larger sizes and moulting becomes less frequent, the probability of recovery will increase. Two steps were taken to adjust for this variability. Firstly, we excluded from consideration those tagged crabs which were less than 135 mm in carapace length when released. Secondly, since catch is the result of selection by the fishery, the remaining actual tag returns were weighted by factors based on the percentage of each size group taken by the fishery. The percentages used were those shown in Figure 4.

The adjusted recoveries resulting from each release from 1955 through 1957 were then treated according to Jackson's method (Ricker, 1958) to provide mean annual survival estimates of 0·510 for the 1955 tagging, 0·462 for the 1956 releases, and 0·465 for the 1957 tagging. In the model we have used a survival rate of 0·48, which is the mean of the three estimates.

Results

The model shown in Table 2 is the result of applying computed rates of survival and fishing to 10,000 male crabs of 135 mm in carapace length. In the first year, the number of male crabs of 135 mm carapace length in the stock is reduced during the summer by a fishing mortality of 0·018 (from Table 1), which results in a catch of 180 crabs and yield of 369 kg. Since the annual survival rate of 0·48 dictates that 4,800 of the

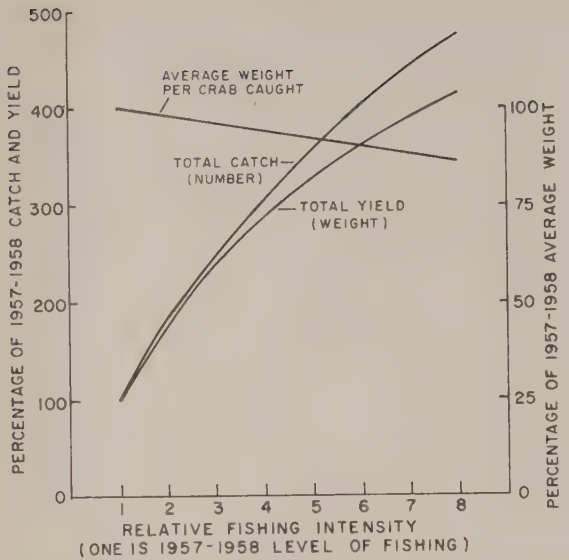

Figure 5. Total catch, yield, and average size at various levels of fishing for eastern Bering Sea king crabs.

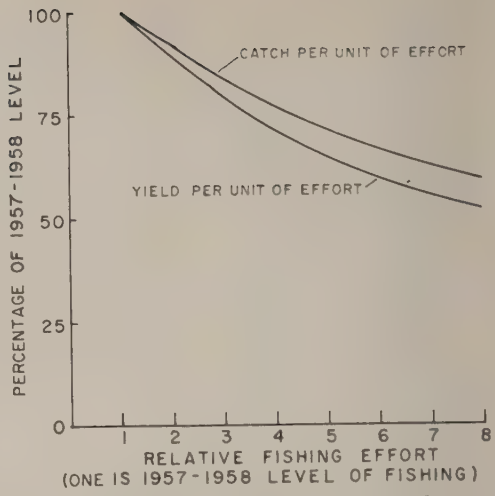

Figure 6. Relationship between fishing effort and success of fishing for eastern Bering Sea king crabs.

10,000 would be available at the beginning of the second year, natural deaths must number 5,020 which is 0·511 of the number remaining after catch. In this manner are shown the annual reduction in numbers of the original recruitment, the natural mortality rates, and the yields.

With the assumption that natural mortality is constant for each size and is independent of fishing intensity, we have developed similar models by subjecting like numbers of crabs to 2, 4, 6, and 8 times the 1957–1958 level of fishing. The fishing mortalities used in these instances are the annual rates equivalent to multiples of the instantaneous rates.

The catch, yield, and average weight of crabs caught are plotted in Figure 5 to show the manner in which these factors can be expected to vary as fishing effort increases. As fishing effort is intensified, both total catch and yield rise rapidly, but average weight per crab caught declines.

The relationship between fishing effort and the success of fishing is indicated in Figure 6. Both the number of crabs caught and the weight yield per unit of effort decline as effort is increased. Since the 1957–1958 fishing effort was largely that of a single Japanese mothership, we can say in general terms that if a fleet of 7 or 8 motherships were to operate, each might be expected to produce about half the present quota of a single mothership, if other factors remained unchanged.

One of our assumptions was that increased fishing would have no adverse effect upon the rate of recruitment. This is to say that the capacity of the stock to reproduce itself will not be damaged. There is some evidence, however, that the group of crabs most sought after by the fishery is the same group that is most actively engaged in reproduction. Indeed, it would appear that it is the congregation of these large non-moulting male crabs in relatively shallow water for the purpose of mating that makes them especially vulnerable to the tangle net fishery. We do not know at which point the reduction of this group might begin to reduce the reproductive capacity of the stock, but we can estimate the effect that various levels of fishing will have upon size composition.

Our discussion of the models has been in terms of a single year-class progressing in time and subjected to various annual rates of loss. The model can also be used to represent all the available size classes present in the population. By taking the numbers of each age-group present at the start of summer, the size composition at various levels of fishing can be predicted (Figure 7). It is apparent that the number of large males will be considerably reduced at the higher levels of fishing, while the effect upon the numbers of small males will be negligible.

Summary

King crabs of the eastern Bering Sea have been under study by the Bureau of Commercial Fisheries since 1953. From a modest beginning, studies were intensified in 1955 and in this report, our initial attempt to assess the effects of fishing on this population is reviewed.

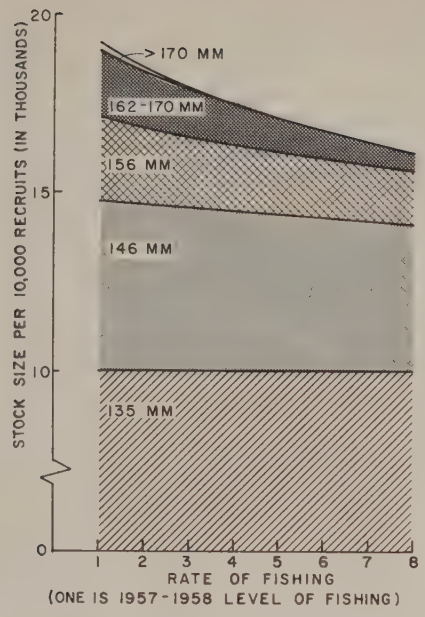

Figure 7. Stock size composition at various levels of fishing for eastern Bering Sea king crabs.

The method used is to take an arbitrary number of crabs at a size when they are generally available and subject them to estimates of growth, fishing, and natural mortality, in yield per recruit models. Models were developed for levels of fishing ranging from 1 to 8 times the average for 1957 and 1958.

The growth parameter used was developed in a study by Weber and Miyahara (1962). Natural death rates were computed by subtracting fishing mortalities from total annual mortality, estimated from tagging experiments. Fishing mortality rates were developed from comparisons of the catch in 1957 and 1958 with abundance estimates developed from otter trawl surveys.

The analyses indicate that the effects of increased fishing above the 1957–1958 level are that total catch and yield rise, but the rate of yield increase lags behind the rate of increase in numbers caught, because average size of crabs in the catch declines.

The relationship of fishing effort and success of fishing is that both the number of crabs caught and weight yield per unit of effort would be expected to decline as effort is multiplied. It would appear that the yield per unit of effort from eight times the 1957–1958 level of fishing would be about half of the 1957–1958 yield per unit of effort.

An extension of the model to show expected size composition of the stock at various levels of fishing is included. The effect is that increases in fishing will reduce the number of large male crabs but will have negligible effect upon the number of the smaller-sized commercially exploited males.

An important consideration, and one for which we do not yet have adequate information, is whether the increased fishing would have adverse effects upon the rate of recruitment.

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Résumé of discussion on the paper

Prof. Nikolsky, drawing attention to the season and frequency of moulting, enquired at what carapace length did the change occur from annual to every second year. Mr. Miyahara replied that: –

at carapace length			85–90 mm	moulting was annual;
-	–	–	135 mm	a proportion moulted less frequently than annually;
-	–	–	150 mm	50% moulted every other year;
-	–	–	170 mm	and over moulting was every second year.

The males moulted in March/April and the females in May/June. In general males moulted before mating, but these factors showed some area-to-area variations.

Dr. Cole enquired regarding the methods used to determine the season of moulting. Mr. Miyahara said that negative evidence had been used, namely absence of certain categories from the catch.

Mr. Simpson drew a parallel with *Cancer pagurus* in which, however, the females moult before the males. The mature female, some time before moulting, is attended by a male which stays with her until she has moulted. Mating then occurs and later the male moults. In reply Mr. Miyahara said that with *Paralithodes* it was different. The males which mated did not cast until the succeeding year.

Dr. Cole enquired as to the causes of the high natural mortality. Mr. Miyahara said he had no direct evidence; mortality seemed to be concentrated

mainly into the period of moult when the crab was very vulnerable.

Prof. KORRINGA, drawing attention to estimates of fishing mortality, based on tag returns, asked if these were reliable. In reply Mr. MIYAHARA said that he thought most recovered tags were returned.

Dr. VILELA enquired as to the depth distribution of *Paralithodes*. Mr. MIYAHARA said that in the eastern Bering Sea the king crabs were found in depths of 30 to 60 fm, whilst south of the Peninsula the distribution was in depths of from 10 to 100 fm.

Mr. BOEREMA, drawing attention to the total mortality (estimated at about 50%) and to the low fishing mortality (assumed, amongst small individuals, to be 15%), asked if these varied with moult frequency. In reply Mr. MIYAHARA said that natural mortality was indeed less with lower moult frequency.

Prof. NIKOLSKY enquired regarding predators. Replying, Mr. MIYAHARA indicated that he had no direct evidence but suspected that, at the moult, halibut and *Cottus* took some crabs. Others were destroyed through cannibalism.

Dr. COLE asked if there was any evidence of the level of fishing affecting the reproductive capacity of the stock. Mr. MIYAHARA, replying, said he had no such information. In *Paralithodes* mature males were either "maters" or "non-maters" and there was some evidence that the distribution of these classes was different.

Dr. TIEWS asked how long it took for the shell to harden after the moult. Replying, Mr. MIYAHARA indicated that "hardness" was a relative term but that the shell was well calcified after two weeks, although it was six months before the ventral surface assumed the darker colour associated with the return to marketable conditions after moulting.

Mr. PROKHOROV, referring to the preference for males in the commercial fishery, asked if this affected the sex ratio. Mr. MIYAHARA had no evidence of this being the case.

BLANCO LUNO A/S, KBH

Reprint from THE TEXAS JOURNAL OF SCIENCE, Vol. XVII, No. 2, June, 1965

Range Extension of the Sipunculoidean Annelid *Phascolion strombi* (Montagu) in the Gulf of Mexico

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Phascolion strombi (Montagu) is a widespread, cosmopolitan species which occurs in the western Atlantic from Labrador to the West Indies (Gerould, 1913; Hyman, 1959; and Miner, 1950). Although his identification of them was tentative, Hedgpeth (1954) reported small specimens from shells of *Nassarius vibex* in Caminada Bay, Louisiana.

This annelid was collected incidentally at two locations by Bureau of Commercial Fisheries personnel during routine biological sampling in Galveston Bay (Texas) and the adjacent near-shore Gulf of Mexico. The author is unaware of any previous record of its occurrence in the Galveston area.

Seventy-five specimens were collected November 4, 1963, on silty-sand bottom at a depth of 36 feet (6 fathoms) in the Gulf near the Galveston jetties (lat. 29° 20′ N., long. 94° 36.6′ w.). Water temperature and salinity were 23 C. and 32.1 ppt., respectively. The worms ranged in length from 14 to 21 mm. (averaged 17 mm.) and were observed to be occupying empty, 6-mm.-long shells of *Nassarius acutus*.

A single specimen was collected December 3, 1963, from 6 feet (1 fathom) of water on silty-clay bottom in Upper Galveston Bay (Lat. 29° 34.3′ N., long. 94° 57.9′ W.). It was 22 mm. long and occupied the empty shell of *Epitonium rupicola*. The water temperature was 13.6 C. and the salinity 23.3 ppt.

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Made in United States of America
Reprinted from TRANSACTIONS OF THE AMERICAN FISHERIES SOCIETY
Vol. 94, No. 3, July 1965
pp. 236–242

Food and Feeding Habits of Skipjack Tuna (*Katsuwonus pelamis*) from the Marquesas and Tuamotu Islands

EUGENE L. NAKAMURA

Food and Feeding Habits of Skipjack Tuna (*Katsuwonus pelamis*) from the Marquesas and Tuamotu Islands

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ABSTRACT

Stomach samples were examined from 603 skipjack (*Katsuwonus pelamis*) caught by live-bait fishing in waters surrounding the Marquesas and Tuamotu Islands from 1957 to 1959. The principal crustacean food consisted of stomatopods and megalops, while the main molluscan item was squid. The major fish items were acanthurids, gempylids, lutjanids, nomeids, scombrids, serranids, and synodontids. Larger skipjack ate comparatively more fish and less crustaceans. As expected, those from inshore areas had eaten more reef-originating organisms than had skipjack from areas farther offshore. No differences were found in food of the two sexes. Skipjack appeared to have heavy feeding periods in midmorning and in late afternoon hours, with a slack period during midday. This feeding pattern may be related: (1) to the distribution and abundance of forage organisms and zooplankton and their diurnal movements or (2) to a satiaton of the food drive during midday. Confirmation of some of the trophic links in the food chain of skipjack was obtained by examination of the stomachs of the ingested fishes. The occurrence of juvenile tuna in the skipjack stomachs was higher than those reported from previous food studies of tuna from other areas.

INTRODUCTION

An investigation of the tuna resources around the Marquesas and Tuamotu Islands (Figure 1) was undertaken during 1956–59 by the Bureau of Commercial Fisheries Biological Laboratory at Honolulu. One of the projects of this investigation was a study of the food and feeding habits of skipjack tuna (*Katsuwonus pelamis*) caught during the surveys in these waters. This paper presents the results of this study.

Data obtained by the laboratory's research vessels and by chartered fishing boats during cruises to this area have been published by Austin (1957), Wilson and Rinkel (1957), Wilson, Nakamura, and Yoshida (1958), and Yoshida (1960).

The word *tuna* is used to refer to fishes of the following genera: *Thunnus, Katsuwonus, Euthynnus*, and *Auxis*.

MATERIALS AND METHODS

Cruises on which skipjack stomach samples were obtained are listed in Table 1. The fish were captured by live-bait fishing (June, 1951). On *Charles H. Gilbert* cruise 32 and part of *Charles H. Gilbert* cruise 35, stomach samples were obtained only from females. To remove possibilities of sex bias in food analyses, stomach samples from both sexes were collected during the latter part of *Charles H. Gilbert* cruise 35 and on all subsequent cruises. Whenever possible, five males and five females were sampled from each school. The stomachs were cut out intact, labeled, placed in a cloth bag, and then preserved in 10% formalin. A slit was made in the stomach wall of large specimens to facilitate preservation.

A total of 603 skipjack stomachs was obtained from 81 schools (Table 1). Sampling was conducted primarily during inshore and offshore surveys in the Marquesas area (Figure 1) and secondarily in the Tuamotu area. Collections from the Tuamotu area are included with those from the Marquesas. They consist of 45 samples obtained from two schools each on *Charles H. Gilbert* cruises 32, 35, and 38.

In the laboratory the stomach contents were identified, and the volume of each kind of food was measured by water displacement.

Ingested fishes, which were not readily identifiable because of the effects of digestive processes, were cleaned of muscle tissue so that the vertebrae could be examined. The vertebrae were stained with alizarin and compared with a collection of named specimens which similarly were stained and preserved in glycerin. Whenever possible the stomach contents of the ingested fishes were examined qualitatively.

The Marquesan sardine (*Harengula vittata*) was used as live bait. It was easily identified as none was found in advanced stages of digestion. Because of this, all Marquesan sardines

found in skipjack stomachs were assumed to have been thrown overboard during fishing. Consequently, sardine occurrences in skipjack stomachs were disregarded.

FOOD COMPOSITION

Fish, molluscs, and crustaceans are the three most important categories of food eaten by tuna (Hotta and Ogawa, 1955; McHugh, 1952; Ronquillo, 1953; Tester and Nakamura, 1957; Watanabe, 1958; Welsh, 1949; and others). The only food item found in the present investigation that does not fall into one of these categories is the tunicate. Tunicates were found in six stomachs obtained on *Charles H. Gilbert* cruise 32. They also have been found in stomachs of other species of tuna (Alverson, 1963; Reintjes and King, 1953; King and Ikehara, 1956; Krumholz, 1959; Watanabe, 1958).

A detailed list of the food items found in the skipjack stomachs is presented in Table 2. Of the crustaceans, stomatopods had the highest percentage occurrence, while squid was the most frequently found mollusc. Surprisingly, juvenile tuna (the only scombrids found) had the highest overall occurrence among the 33 identified families of forage fish.

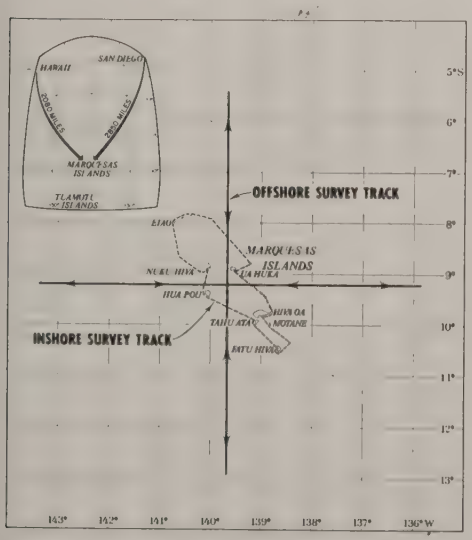

FIGURE 1.—Offshore and inshore survey tracks in the Marquesas Islands.

TABLE 1.—*Summary of skipjack stomach samples taken in the Marquesas and Tuamotu Islands area (CHG* = Charles H. Gilbert; *HMS* = Hugh M. *Smith)*

Cruise number	Cruise period	Schools sampled	Stomachs sampled	Empty stomachs	Stomachs with food
CHG-32	11 Jan.–22 Mar. 1957	28	138	13	125
CHG-35	2 Oct.–14 Dec. 1957	14	105	30	75
HMS-43	3 Jan.–25 Feb. 1958	14	127	41	86
CHG-38	7 Feb.–2 May 1958	14	123	25	98
HMS-45	28 Mar.–23 Jun. 1958	11	110	36	74
	Total	81	603	145	458

VARIATION WITH SIZE

Few large fish were sampled. Approximately 70% of the samples were obtained from fish between 45 and 55 cm long (Table 3).

As the size of the skipjack increased, the percentage occurrence of crustaceans declined while that for fish increased (Table 3). The percentages for molluscs decreased for intermediate-sized skipjack and increased for larger skipjack. Differences in diet among various sizes of skipjack have also been found in Hawaii by Yuen (1959). He found among the larger of the species a greater dependence on fish for their food and a lesser reliance on molluscs and crustaceans. Similar results have been obtained for skipjack in the eastern tropical Pacific by Alverson (1963).

Only 28 of the 603 stomachs contained volumes greater than 50 cc, and only six over 100 cc. The latter six were among the 70- to 80-cm fish. Comparison of volumes of stomach contents between Marquesan and Hawaiian skipjack (Figure 2) showed greater values from Hawaii. These differences are attributable to fish size, for approximately 70% of the fish from the Marquesas were smaller than 60 cm, while over 70% from Hawaii were larger than 60 cm. Larger volumes of stomach contents with an increase in size in central Pacific skipjack also have been reported by Waldron and King (1963) and for other species of tuna by King and Ikehara (1956) and by Iversen (1962).

VARIATION WITH SEX

A comparison of the stomach contents of males and females was made, using data for schools from which samples of both sexes were taken. No significant differences in their

TABLE 2. *Occurrence of items in stomachs of skipjack from the Marquesas and Tuamotu Islands area (asterisks denote reef-originating forms)*

Item	Cruise number										Total	
	CHG-32		CHG-35		HMS-43		CHG-38		HMS-45			
	F[1]	%[2]	F	%	F	%	F	%	F	%	F	%
Crustacea	102	81.6	54	72.0	67	77.9	74	75.5	34	45.9	331	72.3
Amphipoda	14	11.2	1	1.3	1	1.2	4	4.1			20	4.4
*Stomatopoda	94	75.2	52	69.3	54	62.8	67	68.4	24	32.4	291	63.5
Euphausiacea	4	3.2			16	18.6	3	3.1	10	13.5	33	7.2
*Megalopa	37	29.6	17	22.7	11	12.8	15	15.3	4	5.4	84	18.3
Shrimp	4	3.2	1	1.3	1	1.2	6	6.1	1	1.4	13	2.8
*Phyllosoma	7	5.6			4	4.7	6	6.1			17	3.7
*Juvenile lobster									1	1.4	1	0.2
Unidentified decapod	2	1.6									2	0.4
Mollusca	35	28.0	10	13.3	18	20.9	20	20.4	28	37.8	111	24.2
Heteropoda	1	0.8	1	1.3			1	1.0			3	0.7
Pteropoda			1	1.3							1	0.2
Squid	33	26.4	8	10.7	18	20.9	19	19.4	28	37.8	106	23.1
Argonaut	2	1.6									2	0.4
Unidentified mollusc			1	1.3							1	0.2
Tunicata	6	4.8									6	1.3
Fish	110	88.0	58	77.3	54	62.8	75	76.5	55	74.3	352	76.9
Idiacanthidae			1	1.3							1	0.2
*Synodontidae	39	31.2	16	21.3	10	11.6	9	9.2	10	13.5	84	18.3
Myctophidae									8	10.8	8	1.7
*Belonidae	4	3.2									4	0.9
Exocoetidae					2	2.3			2	2.7	4	0.9
*Fistularidae					2	2.3	1	1.0			3	0.7
*Holocentridae	5	4.0	7	9.3			6	6.1			18	3.9
*Sphyraenidae	3	2.4									3	0.7
*Serranidae	33	26.4	8	10.7	7	8.1	15	15.3	1	1.4	64	14.0
*Priacanthidae							3	3.1			3	0.7
*Carangidae	46	36.8	4	5.3			5	5.1	2	2.7	57	12.4
Bramidae	4	3.2							1	1.4	5	1.1
Coryphaenidae	2	1.6	1	1.3							3	0.7
Emmelichthyidae	13	10.4									13	2.8
*Lutjanidae	36	28.8	8	10.7	3	3.5	9	9.2	2	2.7	58	12.7
*Mullidae	17	13.6	1	1.3	4	4.7	2	2.0			24	5.2
*Kyphosidae							1	1.0	1	1.4	2	0.4
*Chaetodontidae	8	6.4	9	12.0	4	4.7	2	2.0			23	5.0
*Pomacentridae			1	1.3							1	0.2
*Ammodytidae	12	9.6	2	2.7							14	3.1
*Acanthuridae	12	9.6	10	13.3	7	8.1	22	22.4	1	1.4	52	11.4
Gempylidae	16	12.8	4	5.3	14	16.3	14	14.3	8	10.8	56	12.2
Scombridae	31	24.8	22	29.3	38	44.2	32	32.7	20	27.0	143	31.2
*Blenniidae	30	24.0	2	2.7	2	2.3	2	2.0			36	7.9
Nomeidae	25	20.0	2	2.7	3	3.5	17	17.3	4	5.4	51	11.1
*Scorpaenidae	1	0.8	1	1.3							2	0.4
Platycephalidae	1	0.8			1	1.2					2	0.4
*Dactylopteridae					2	2.3	1	1.0	4	5.4	7	1.5
Pegasidae					1	1.2					1	0.2
*Balistidae	5	4.0	4	5.3	1	1.2	17	17.3	5	6.8	32	7.0
*Monocanthidae	2	1.6									2	0.4
*Ostraciontidae							1	1.0			1	0.2
*Diodontidae					1	1.2					1	0.2
*Leptocephalus							1	1.0			1	0.2
Unidentified fish	62	49.6	20	26.7	12	14.0	20	20.4	21	28.4	135	29.5

[1] Number of stomachs in which found.
[2] Percentage occurrence in stomachs containing food.

quantity or composition were found. The difference between the average volumes for the two sexes was only 0.5 cc, and the percentage of occurrence of empty stomachs was very similar. 27.4% for females and 26.2% for males.

VARIATION WITH AREA

Most of the samples were obtained during the inshore surveys (Figure 1). Data from these and from the few offshore samples suggest that no relation exists between volumes of stomach contents and distance from land.

To assess areal differences in the composition of the stomach contents, food items were classified as reef-originating and nonreef-originating. The groups marked with an asterisk in Table 2 were judged to be primarily reef-originating, that is, they spend their adult life on reefs or in other nonpelagic areas but their larval or juvenile stages in pelagic environments. Percentages of food items classified as reef-originating forms in skipjack caught within the inner, middle, and outer 75-mile sectors of the offshore surveys were 61.5, 39.9, and 8.8, respectively. As one might expect, skipjack captured close to the islands had fed upon reef-originating organisms to a much greater extent than those caught farther offshore.

TABLE 3.—*Summary of food of various sizes of skipjack*

Fork length (cm)	Stomachs examined			Food item							
				Crustacea		Mollusca		Tunicata		Fish	
	With food	Empty	Total	F[1]	%[2]	F	%	F	%	F	%
35.0–39.9	0	1	1								
40.0–44.9	32	12	44	24	75.0	7	21.9			20	62.5
45.0–49.9	208	75	283	160	76.9	46	22.1	2	1.0	165	79.3
50.0–54.9	114	23	137	104	91.2	20	17.5	3	2.6	75	65.8
55.0–59.9	16	3	19	11	68.8	1	6.2	1	6.2	14	87.5
60.0–64.9	11	1	12	8	72.7	1	9.1			10	90.9
65.0–69.9	28	0	28	12	42.9	12	42.9			23	82.1
70.0–74.9	17	12	29	6	35.3	8	47.1			16	94.1
75.0–79.9	27	15	42	5	18.5	12	44.4			24	88.9
80.0–84.9	3	2	5	1	33.3	2	66.7			3	100
85.0–89.9	0	1	1								
Total[3]	456	145	601	331	72.6	109	23.9	6	1.3	350	76.8

[1] Number of stomachs in which found.
[2] Percentage occurrence in stomachs containing food.
[3] Lengths not available for two skipjack.

VARIATION WITH TIME

The combined data permitted examination of diurnal variations in stomach contents. Average volumes of stomach contents were computed for each hour of the day that the schools were fished (Figure 2). Appropriate zone times were used (+9 zone time for the area east of 142°30′ W and +10 zone time for the area west of that longitude).

The volumes exhibit a morning peak followed by a midday low and another peak in late afternoon. Similar results were obtained for Hawaiian skipjack as shown in Figure 2 (data from Yuen, 1959), although the morning peak occurred 2 hours later than for the Marquesan data.

The average number of forage fish per stomach from skipjack caught at various hours of the day (Figure 2 and Table 4) showed variations similar to that for the volumes. The variations for Mollusca were also similar. Variations for Crustacea showed no midday minimum (Table 4).

A midday minimum was found not only in volumes of stomach contents and in number of forage fish per stomach but also in zooplankton abundance. The downward movement by many zooplankters during daylight hours is a well-known phenomenon in tropical and subtropical oceans. As a result of this movement, zooplankton volumes for a 24-hour period exhibit a diel rhythm approximating a sinusoid, with the maximum around midnight and minimum around noon. Zooplankton volumes for daylight hours obtained from a 24-hour station in the Marquesas on *Hugh M. Smith* cruise 43 are shown in Figure 2. The night values, as shown in the inset, increased to a maximum of 64 cc/1,000 m^3 at 2200 hours and decreased thereafter to the minimum shown at 1000 hours. Similarly, a minimum between 1000 and 1400 hours and a maximum between 2200 and 0300 hours were found in zooplankton volumes from five other 24-hour stations in the Marquesas (Wilson, Nakamura, and Yoshida, 1958).

Evidence has been found in Hawaiian waters that larval fish, and possibly also juvenile fish, exhibit diel variations in abundance similar to those of invertebrate zooplankton. Larval fish show a minimum abundance around noon and two maxima at night, one before and one after midnight (unpublished data).

The diurnal feeding pattern of skipjack may be associated with the availability of food. Zooplankters move downward during the early daylight hours, presumably to reach a preferred level of illumination. Since they serve as food for the forage organisms, some of the latter, also seeking lower levels of illumination, will tend to move downward and thus minimize their availability to the surface-dwelling skipjack. The minima occur around noon, the period when sunlight penetration is greatest, when zooplankters are deepest, and when forage fish are least available to skipjack. During late daylight hours the zooplankters and forage fish begin their upward movement. Skipjack begin feeding heavily in the late

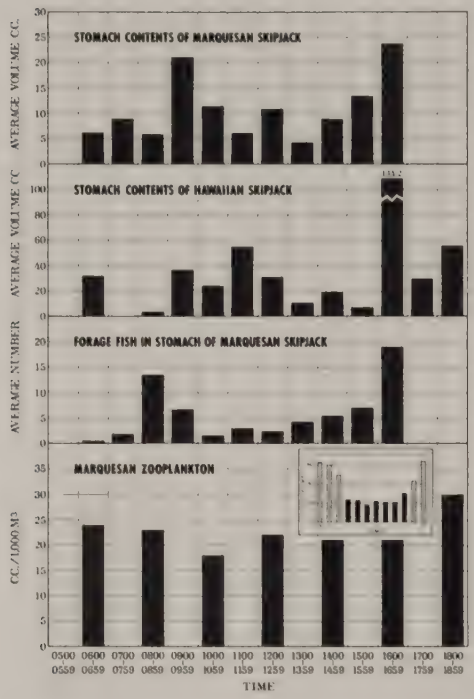
STOMACH CONTENTS OF MARQUESAN SKIPJACK
AVERAGE VOLUME CC.
STOMACH CONTENTS OF HAWAIIAN SKIPJACK
AVERAGE VOLUME CC
FORAGE FISH IN STOMACH OF MARQUESAN SKIPJACK
AVERAGE NUMBER
MARQUESAN ZOOPLANKTON
CC./1000 M3
0500 0559 0600 0659 0700 0759 0800 0859 0900 0959 1000 1059 1100 1159 1200 1259 1300 1359 1400 1459 1500 1559 1600 1659 1700 1759 1800 1859
TIME

FIGURE 2.—Diurnal variation in volumes of stomach contents of Marquesan skipjack, volumes of stomach contents of Hawaiian skipjack (data from Yuen, 1959), number of forage fish in stomachs of Marquesan skipjack, and Marquesan zooplankton volumes.

afternoon hours before dark as food becomes more available.

Diurnal variation of the volumes of stomach contents also may reflect the effects of satiation to food. Skipjack, starting the day with their stomachs empty, feed actively during the early morning hours, and food consumption reaches a peak sometime before noon. A period of satiety occurs midday while digestive processes reduce the stomach contents. As the stomach empties, skipjack forage again, and the volume reaches a second peak prior to darkness.

Seasonal variations in the occurrence of the various food groups are shown in Figure 3 and in Table 2. The occurrence of forage did not vary greatly from season to season. (Seasonal references are for the Southern Hemisphere.) Crustacea was low in the fall (*Hugh M. Smith* cruise 45) and highest in the summer (*Charles H. Gilbert* cruise 32 and *Hugh M. Smith* cruise 43). Mollusca was lowest in spring (*Charles H. Gilbert* cruise 35) and highest in fall (*Hugh M. Smith* cruise 45).

STOMACH CONTENTS OF INGESTED FISHES

Confirmation of some of the trophic links in the food chain of skipjack was obtained by examining the food of the ingested fishes. The examination revealed the dependence of forage fishes upon planktonic organisms (Table 5). All of the organisms listed as food for the ingested fishes in the table have been captured in plankton nets. The category Gempylidae represents a single snake-mackerel. Its stomach contained a squid, a smaller gempylid, a small dolphin (*Coryphaena hippurus*), and a small skipjack. The dolphin's stomach contained an unidentified larval fish, while the young skipjack's had copepods. The small gempylid's stomach was empty.

TUNA AS FORAGE FOR TUNA

The occurrence of juvenile tuna ranged from 24.8 to 44.2% for the samples from each of the cruises (Figure 3). Of the stomachs containing food, 143 (31.2%) contained juvenile tuna, while 57 (12.4%) contained juvenile skipjack. Percentage occurrence of juvenile skipjack was computed only from stomachs containing positively identified skipjack. Remains of tuna vertebrae for which specific identifications were doubtful were classified with the juvenile tuna group. Therefore, the percentages for juvenile skipjack in Figure 3 are conservative.

TABLE 4.—*Summary of food of skipjack caught at various hours of the day*

Time	Stomachs examined	Crustacea		Mollusca		Fish	
		Number found	Number per stomach	Number found	Number per stomach	Number found	Number per stomach
0600–0659	15	13	0.9	3	0.2	6	0.4
0700–0759	28	24	0.9	6	0.2	51	1.8
0800–0859	40	72	1.8	10	0.2	540	13.5
0900–0959	108	550	5.1	49	0.5	724	6.7
1000–1059	49	200	4.1	8	0.2	79	1.6
1100–1159	74	335	4.8	12	0.2	221	3.0
1200–1259	19	136	7.2	3	0.2	46	2.4
1300–1359	55	262	4.8	8	0.1	234	4.3
1400–1459	93	363	3.9	21	0.2	500	5.4
1500–1559	82	626	7.6	38	0.5	579	7.1
1600–1659	40	1806	45.2	15	0.4	759	19.0

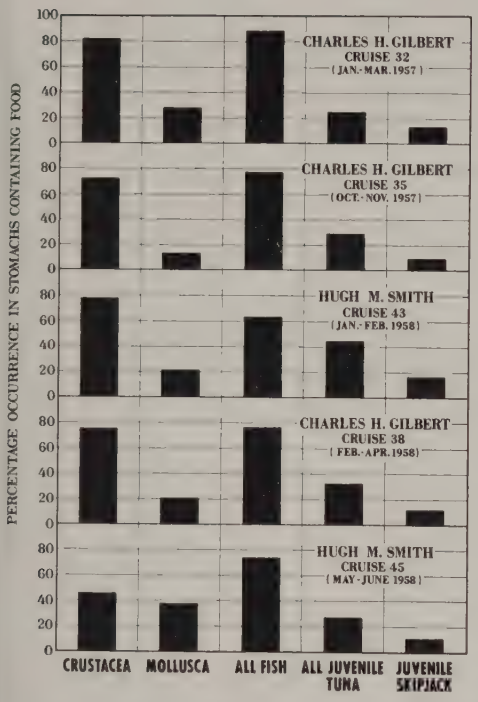
PERCENTAGE OCCURRENCE IN STOMACHS CONTAINING FOOD
CHARLES H. GILBERT CRUISE 32 (JAN.-MAR. 1957)
CHARLES H. GILBERT CRUISE 35 (OCT.-NOV. 1957)
HUGH M. SMITH CRUISE 43 (JAN.-FEB. 1958)
CHARLES H. GILBERT CRUISE 38 (FEB.-APR. 1958)
HUGH M. SMITH CRUISE 45 (MAY-JUNE 1958)
CRUSTACEA
MOLLUSCA
ALL FISH
ALL JUVENILE TUNA
JUVENILE SKIPJACK

FIGURE 3.—Percentage occurrence of various food items in skipjack stomachs.

Measurable specimens of ingested juvenile tuna ranged from 2 to 15 cm long. The range for skipjack was about 4 to 15 cm long. The highest number of juvenile tuna found in a single stomach was 47; the second highest was 31. Both high counts occurred only once. Single occurrences were observed in 52 cases. In addition to juvenile skipjack, several *Euthynnus* sp., several *Auxis* sp., and one *Thunnus albacares* were identified.

The occurrence of tuna as forage was considerably greater in the samples of this study than in those of previous tuna food studies. King and Ikehara (1956) reported skipjack occurrences of 3.9% and 0% in the stomachs of 439 yellowfin (*Thunnus albacares*) and 166 bigeye (*Thunnus obesus*), respectively, caught by longline in the central Pacific. Assuming that each occurrence of tuna (six species were identified) was in a separate stomach, their report implies that 8.4% of the yellowfin stomachs contained some species of tuna, while only 3.0% of the bigeye stomachs did. In a study of 1,097 yellowfin caught by trolling, live-bait fishing, and longlining in the central Pacific, Reintjes and King (1953) found skipjack in 1.5% of the stomachs, while another 3.9% contained some species of tuna. In 519 skipjack caught by the live-bait method from Hawaiian waters, Yuen (unpublished data) found juvenile tuna in 10.0% of the stomachs. Less than 12% of 707 stomachs of central Pacific skipjack caught by various methods were reported to contain tuna (Waldron and King, 1963). Skipjack were found in 55 (7.8%) of their samples. Alverson (1963) reported finding skipjack in only one yellowfin stomach and none in skipjack stomachs of 2,846 yellowfin and 1,010 skipjack caught by live-bait fishing and by purse-seining in the eastern tropical Pacific. Assuming again that each occurrence was in a separate stomach, his data show other species of tuna (four species identified) in 112 (3.9%) yellowfin stomachs. Only one species of tuna was found by Alverson in the skipjack (*Auxis* sp. in two stomachs). Koga (1958a), reporting on longline-caught tuna from the western Indian Ocean, found juvenile skipjack in 20.9% of 216 yellowfin, in 21.3% of 67 bigeye, and in 4.7% of 53 albacore (*Thunnus*

TABLE 5.—*Stomach contents of fishes ingested by skipjack*

Ingested fish	Stomach contents
Skipjack (*Katsuwonus pelamis*)	Mysids, euphausiids, amphipods, megalops, copepods (*Euchaeta, Scolecithrix*, others), squid, fishes (synodontid, others)
Euthynnus sp.	Amphipods, copepods (*Euchaeta, Scolecithrix*, others), fishes (synodontid, others)
Yellowfin (*Thunnus albacares*)	Fish (synodontid)
Unidentified species of tuna	Euphausiids, amphipods, copepods, fishes
Acanthuridae	Heteropods
Carangidae	Euphausiids, copepods (*Candacia*), fish (synodontid)
Gempylidae	Squid, fishes (*Coryphaena hippurus, Katsuwonus pelamis*, and gempylid)
Holocentridae	Shrimps, copepods (*Candacia*, cyclopoids, others)
Lutjanidae	Amphipods, shrimps, copepods (*Sapphirina*, others), chaetognaths
Myctophidae	Amphipods, ostracods, euphausiids, copepods (*Scolecithrix, Oncaea*, others), fishes
Nomeidae	Amphipods, copepods, annelids, chaetognaths
Serranidae	Copepods (*Oncaea*, others)
Unidentified fish	Shrimps, copepods (*Candacia*, others)

alalunga). From his examination of longline-caught tuna in the vicinity of the Gilbert and Fiji Islands, Koga (1958b) reported juvenile skipjack in 13.3% of 142 yellowfin and in 11.3% of 53 bigeye.

The above examples indicate that tuna serve as an important food item for other tuna in certain areas. Specifically, skipjack appear to be comparatively more important as forage for tuna in the western Indian Ocean and around the Gilbert, Fiji, and Marquesas and Tuamotu Islands than in other areas.

The fact that juvenile skipjack occur so frequently in the stomach samples obtained by live-bait fishing in the Marquesas and by longline in the western Indian Ocean waters implies they inhabit both the surface and lower depths. Adult skipjack, on the other hand, generally are believed to inhabit the upper ocean layers for they seldom are caught by longlines which fish the deeper waters.

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Made in United States of America
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COLORATION OF THE SCOMBRID FISH *EUTHYNNUS AFFINIS* (CANTOR).—Observations of living tuna have revealed color features seldom seen in dead specimens. Such features have been reported for skipjack tuna, *Katsuwonus pelamis* (L.), by Strasburg and Marr (1961, Copeia 1961 (2): 226–228) and by Nakamura (1962, Copeia 1962 (3):449–505) and for Pacific bonito, *Sarda chiliensis* (Cuvier), by Magnuson and Prescott (MS). Permanent and transient color patterns of a third species of tuna, *Euthynnus affinis* (Cantor) (= *Euthynnus yaito* Kishinouye), have been observed on specimens captured by trolling and maintained in captivity at Kewalo Basin, Honolulu, Hawaii, using methods and facilities similar to those described by Nakamura (*op. cit.*). Observations from above the surface of the tanks and through glass windows in the sides of the tanks were made during 1963 on specimens whose fork lengths were about 40 cm and whose weights were about 1 kg.

The dorsal surface of *E. affinis* varies from dark blue to yellowish green. The ventral surface of the body is silvery white. A pattern of black and bluish-white stripes is prominent on the scaleless portion of the dorsolateral and dorsoposterior areas of the body (Figs. 1, 2, and 3). Two black spots occur on the head, one at the apex of the posterior margin of the operculum, and a second on the posteroventral rim of the orbit (Figs. 1, 2). The first dorsal fin has a black tip and a dull white leading edge. The tips of the ventral fins are white.

Fig. 1. Faint vertical bars on the flank and dark spots ventral to the pectoral fin of *Euthynnus affinis* immediately after feeding.

The darkness of the dorsal surface varies among individuals in the same tank, but in general the color appears to be a response to the darkness of the background. In recently cleaned tanks, which are light blue, *E. affinis* tend to be yellowish green dorsally. In uncleaned tanks, which are dark greenish brown, they tend to be dark blue dorsally except for the dorsal area of the caudal peduncle, which remains yellowish.

The yellow at the dorsal surface of the caudal peduncle has been observed also in *K. pelamis*.

The stripes on the dorsolateral and dorsoposterior regions begin a short distance away from the middorsal line and extend obliquely downward to the lateral line. Two or 3 of the dark stripes may extend below the lateral line and continue forward parallel to the longitudinal axis of the body until they reach the corselet. Some of the stripes may anastomose or be broken into short sections or into spots. No 2 patterns appear exactly alike, and they may vary among fish and between sides of a single fish. The uniqueness of the patterns has been used by us to identify individuals in our tanks. The general orientation of these stripes may serve as a social releaser to the species in differentiating its own kind from other scombrids which resemble it, such as species of *Sarda* and *Auxis*.

The function, if any, of the 2 permanent black spots on the head is not obvious. However, the one on the orbit may reduce the glare or the amount of light reflected up into the eye from the ventral rim of the orbit. On sunny days, a bead of light can be seen often on the ventral portion of the iris

Fig. 2. Bead of light on the ventral portion of the iris of *Euthynnus affinis*.

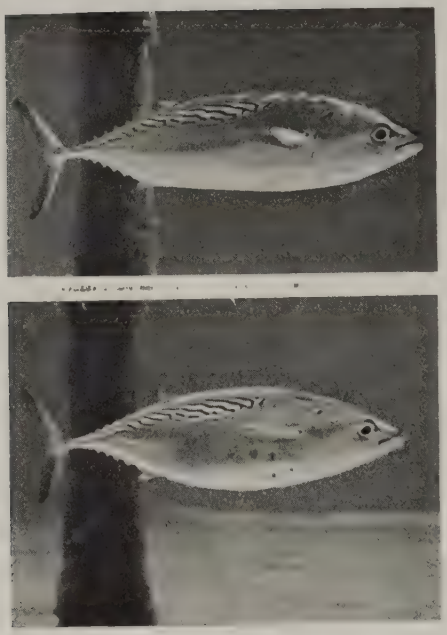

Fig. 3. Upper panel: *Euthynnus affinis* before feeding. Lower panel: Same fish after feeding.

(Fig. 2) or on the ventral rim of the orbit. Light is apparently focused there by the lens. When clouds cover the sun or when the fish swims in shadows, this bead of light is not seen. Reduction of reflection into the eye by the black spot on the orbit would be particularly effective when the fish is swimming towards the surface, at which time the position of this bead of light is likely to shift from ventral to posteroventral. This bead of light has been seen also on fishes which do not possess the black spot on the rim of the orbit (*Seriola* sp. and *Coryphaena hippurus* L.).

These opercular and orbital black spots have been observed also on the following scombrids: *K. pelamis, Sarda chiliensis, S. orientalis* (Temminck and Schlegel), *Thunnus albacares* (Bonnaterre), *Auxis thazard* (Lacépède), and *A. rochei* (Risso).

In addition to the permanent coloration of *E. affinis* described above, 3 transient color patterns or markings have been observed: black spots ventral to the pectoral fins (Figs. 1, 2, 3), faint vertical bars on the flanks (Fig. 1), and a yellowish middorsal stripe. All of these color features are observable during feeding. Their occurrence suggests that they may act as social releasers to signal the presence of food to other members of the school.

The number of spots below the pectoral fins varies. One to 11 spots on a side have been seen on different individuals during feeding. They become particularly intensified if the fish misses a piece of food and then turns suddenly to make a second pass at the food. Unsatiated individuals which are not actually feeding develop the spots if they are presented food stimuli. For example, water which has been scented by dipping a baitfish in it will release spot formation a few moments after it has been introduced into the tank in the absence of visible food stimuli. Also, the presence of a person looking over the side of the tank stimulates spot formation if the fish have usually been fed by a person standing next to the tank. After the fish are satiated, the black spots persist for a while (Fig. 3) but gradually disappear or become fainter and smaller.

The faint vertical bars (Fig. 1), which can also be induced by food stimuli, do not persist as long as the spots do after satiation. They seem to disappear as soon as the fish are through feeding. The vertical bars of *E. affinis* have never been observed to be as intense as those seen on the flanks of feeding *K. pelamis* (Nakamura, *op. cit.*), feeding *S. chiliensis*, or male *S. chiliensis* in aggressive bouts during courtship (Magnuson and Prescott, *op. cit.*).

The yellowish middorsal stripe extends from the tip of the snout to the second dorsal fin. Its width is approximately half the diameter of the eye. It occurs immediately before and after taking food, and fades rapidly.

A similar middorsal stripe has been observed on feeding *S. chiliensis* (Magnuson and Prescott, *op. cit.*) and on feeding *K. pelamis*.

The coloration of *E. affinis* most likely plays an important role in the behavior of this schooling species. Countershading, response to the background, species identification, glare reduction, and food signaling are some of the functions suggested by the present description.—Eugene L. Nakamura and John J. Magnuson, *U. S. Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii.*

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Reprinted from THE JOURNAL OF PARASITOLOGY
Vol. 51, No. 5, October 1965, p. 689–700

LIFE CYCLE OF *UNCINARIA LUCASI* STILES, 1901 (NEMATODA: ANCYLOSTOMATIDAE) OF FUR SEALS, *CALLORHINUS URSINUS* LINN., ON THE PRIBILOF ISLANDS, ALASKA*

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Colorado State University, Fort Collins

ABSTRACT: The life cycle of *Uncinaria lucasi* in fur seals consists of three basic parts: (1) the free-living phase with eggs and free-living third-stage larvae in the soil; (2) the tissue phase wherein parasitic third-stage larvae occur in all age groups of seals, particularly in the blubber of the belly region, and in the case of females, also in the mammary glands and milk cisterns; and (3) the intestinal phase consisting of fourth-stage larvae, adolescent, and adult worms occurring in the intestine of young pups. Eggs passed in the feces of the pups during the summer do not hatch until fall and the larvae may or may not overwinter, depending on unknown microclimatological factors. Infection of all seals with the tissue phase is primarily percutaneous, entry being mainly through the flippers, but it may take place per os. Infection of young pups with the intestinal phase is through the parasitic third-stage larvae which are passed postpartum in the milk for only a short time. The worms reach adulthood in 13 to 15 days and are lost from all pups when the latter are about 3 months old. Seals do not become reinfected and all adults are free of hookworms.

Fur seals haul ashore on the Pribilof Islands in the Bering Sea to bear their young, beginning in late May and early June and extending to mid-July. A large percentage of the pups harbor adult hookworms in the ileocecal portion of the intestine, resulting in a high mortality. The worms are expelled from the intestine of surviving pups late in the summer. Seals never become reinfected following pubhood.

This paper presents an account of the life cycle of *Uncinaria lucasi* as it was worked out under the difficult conditions on the rookeries and in the laboratory on the Pribilof Islands, and on a pelagic sealing ship operating along the Aleutian Chain.

Received for publication 6 January 1965.

* Based in part on dissertation submitted by junior author to the Graduate Faculty of Colorado State University in partial requirements for the degree of Doctor of Philosophy.

This study was supported in part by a grant from the U. S. Fish and Wildlife Service.

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REVIEW OF LITERATURE

Elliott (1884) reported only ascarids in the stomach of grown seals and a pediculus louse on the pups. He saw no evidence of epidemics among the latter.

Lucas (1899) recorded a high mortality among young pups. The finding of great numbers of hookworms in many young pups led to the conclusion that the parasites were the cause of death. While hookworms were never found in older seals, they were believed to be present but overlooked.

Eggs passed onto the sandy rookeries crowded with seals provided ideal circumstances for propagation of the larvae. Infection occurred, he believed, when larvae transferred from the sand to the fur of parous females and were swallowed by nursing pups. In support of this view was his observation that a preponderance of fat, well-fed, rather than emaciated, starving pups were dying.

He noted that mortality of the pups ceased about the end of August and believed it was associated with movement of them from the rookeries to the shoreline and shallow water

where the eggs of *Uncinaria* perished in the sea instead of falling on the ground to complete development with subsequent infection of the seals.

It was his contention that larvae would not survive the winter on the rookeries. While the manner in which the rookeries become reinfested each spring was unknown, he assumed it occurred from returning infected adult seals, even though no hookworms had ever been found in seals of that age.

Stiles and Hassall (1899) saw "no reason to assume that the life history of the seal *Uncinaria* will be materially different from the life history of *U. vulpis* or *U. duodenalis*."

Olsen (1958) began a study of hookworms in fur seals in 1951. He found mature hookworms in a high percentage of pups of fur seals and Stellar's sea lions (*Eumetopis jubata*). Of 1,426 adult seals and 70 sea lions 1 year of age or older examined, no adult hookworms were found except in one 7- to 8-year-old male sea lion.

Attempts to infect seal and fox (*Alopex lagopus*) pups by mouth or by skin with third-stage larvae of *U. lucasi* hatched in the laboratory and collected from the rookeries failed to produce adult worms in the intestine.

Third-stage larvae were found in great numbers in the soil early in the spring before the seals returned from sea. As the season progressed, the number declined until about the 1st of August by which time they had disappeared. Eggs deposited during the summer began to hatch late in August or early in September, as indicated by the reappearance of larvae in the sand. Larvae may live up to 10 or 11 months on the rookeries. It was believed that the life cycle would be similar to that known for other hookworms.

Five per cent emulsion of cresylic acid in water applied as a spray at the rate of 1 pint/ft^2 destroyed all hookworm larvae. Even so, the mortality of pups, incidence of infection, or number of hookworms in the pups were not lowered as a result of spraying the same sections of two rookeries 2 consecutive years.

Olsen (1959) was unable to find third-stage hookworm larvae in rookery soil in mid-July but they appeared by mid-August. Attempts to isolate larvae from the liver and lungs of two pups were unsuccessful. Larval nematodes recovered from skeletal muscles of a parous seal cow were somewhat similar to third-stage hookworm larvae, but their identity was not established. In view of the absence of larvae in the soil at the time, this phase of the study was not pursued as it seemed unlikely that they would be found in seals when absent from the soil.

Following the studies of Olsen (1958, 1959), Lyons and Olsen (1960) concluded that the available evidence suggested a difference in the life cycle of *U. lucasi* from those known for other hookworms in that the third-stage larvae on the rookeries do not enter the pups by penetrating the skin or by ingestion from the soil to develop into adult hookworms in the intestine. Observations leading them to this conclusion were: (1) finding large fourth-stage larvae in very young pups born on boulders over which seawater had washed during the winter, thus rendering the presence of hookworm larvae most unlikely the following spring; (2) finding only adult hookworms in pups dying on the rookeries instead of a graded series of sizes as might be expected from continuous exposure to infested sand with penetration of the skin by the larvae; (3) inability to infect pups and produce adult worms by placing laboratory-reared third-stage larvae in the stomach and on the skin; (4) inability to find larvae migrating through the lungs and up the trachea as would be expected from cutaneous infection of pups continuously exposed to the infested sand of the rookeries; (5) finding that pups born on sections of rookeries where the larvae had been destroyed earlier by a spray of cresylic acid died in great numbers from uncinariasis; and (6) finding that pups born during the summers of 1959 and 1960 when larval hookworms could not be found in the rookery sand died from severe uncinariasis.

Lyons and Olsen (1962a, 1962b) concentrated on the biology of the hookworms, testing first the probability of prenatal infection. They examined 38 caesarean seal pups for prenatal infection without finding any evidence that it occurred. Failing to find any evidence of prenatal infection, postnatal infection through the milk was discovered (Lyons and Olsen, 1960;

Olsen, 1962; Olsen and Lyons, 1962a; Lyons, 1963).

MATERIALS AND METHODS

Seals, both adults and young pups, served as sources of hookworms and as experimental animals. Pups were obtained from rookeries, born in cages, or taken by caesarean section.

Tissues to be examined for larvae were diced and then baermannized in normal saline, reduced to smaller particles by means of a food chopper or blender, and baermannized or digested by standard artificial means. Milk diluted with water was placed in Baermann funnels, allowing the larvae to settle in the stems. Blood was hemolyzed in 2% formalin and centrifuged to isolate larvae.

Preparturient cows were confined for birth of their pups in individual cages on ground never occupied previously by seals.

Milk to be examined for larvae was stripped by hand from restrained cows. Experimental pups were kept in cages and fed seal milk obtained by means of a stomach pump from glutted pups captured on the rookeries. The milk was heated sufficiently to kill any hookworm larvae that might be present.

Eggs for incubation and hatching were obtained from adult worms recovered from infected dead pups found on the rookeries. They were incubated in dishes containing moist plant material or in hanging drops. First- and second-stage larvae were obtained by rupturing the eggshell by mechanical pressure, killed by heat, fixed in 10% formalin, and cleared in glycerine for detailed study.

Parasitic third-stage larvae for morphological studies and experimental infection of pups were obtained from blubber and mammary glands and from milk. Experimentally infected pups were killed and examined at predetermined times in order to obtain all of the developmental stages of the parasites.

Infection of seal pups with the tissue phase of the parasite was accomplished by placing free-living third-stage larvae on the flippers or introducing them into the stomach. Parasitic third-stage larvae were placed directly into the stomach by intubation.

The 38 caesarean pups previously examined without finding any evidence of prenatal infection by hookworms were considered as being adequate controls for the experiments that followed.

Since the circumstances under which the studies were conducted, and the time and funds available did not permit the collection of elaborate quantitative data, the study presents evidence outlining the course of the life cycle and the times involved for the various stages.

Free-living third-stage larvae were isolated from rookery soil by means of Baermann funnels. Soil nematodes in the samples were killed by adding a few drops of concentrated hydrochloric acid, according to the method of Shorb (1937), leaving the active hookworm larvae.

ANALYSIS OF DATA

A. Development of hookworms

The life cycle of *U. lucasi* consists of three phases in which certain stages of the parasites occur. They are: (1) the free-living phase including eggs and free-living third-stage larvae in the soil; (2) the tissue phase in which parasitic third-stage larvae occur in the subcutaneous fat of all seals and in the mammary glands of females; and (3) the intestinal phase with adult worms in the young pups. In the following description all measurements are given in microns unless otherwise indicated. The range is given first, followed by the average and standard deviation in parentheses.

1. Free-living preparasitic stages in soil

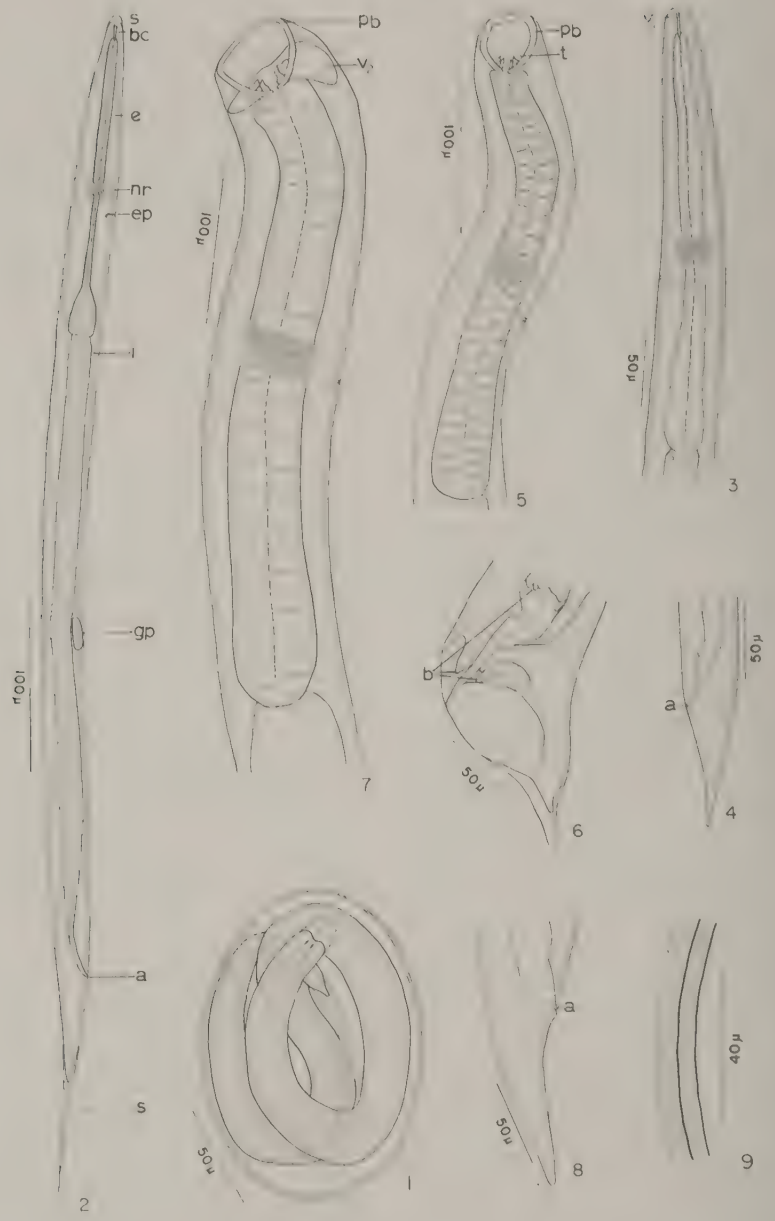
a. *Eggs:* Oval, with hyaline shells, typically ancylostome in appearance, in the 8-celled stage when voided with the feces of pups; 126 to 140 long by 80 to 98 wide (136 SD ± 5.1 by 84.2 SD ± 6.5). Shell consists of three layers. Two inner layers about 1.77 in thickness, somewhat dense in structure; outer layer 0.59 thick and hyaline. Innermost layer bounded on each side by a thick, dark membrane. Outer surface of middle layer without a distinct membrane and demarked from the outer one by a difference in density (Figs. 1, 9).

b. *First-stage larva:* Tadpole stages appear in about 15 hr at constant room temperature of 22 C and fully developed first-stage larvae are present by 24 hr. Internal structures are largely obscured by granules so that only the anterior part of the esophagus and intestine can be distinguished. Ten intact larvae 510 to 630 long (569.5 SD ± 33.2). First-stage larvae distinguished by the short body length, absence of sheath, and presence of numerous granules.

c. *Second-stage larva:* After 40 hr incubation, the first molt occurs within the egg and the second-stage larvae appear within the free cuticular sheath. Granules still obscure much of the internal anatomy; however, the esophagus can be seen clearly. Fifteen larvae 600 to 690 long (637 SD ± 24.7). Esophagi of five 150 to 167 long (157.1 SD ± 7.3). Second-stage larvae slightly longer than first-stage, show esophagus more clearly, and are enclosed in a single sheath.

d. *Unhatched third-stage larva:* Second molt occurs after about 60 hr incubation, resulting in third-stage larva with short, blunt tail and enclosed in two sheaths (Fig. 1). Buccal capsule (Fig. 2, bc) appears as two spear-like projections continuous posteriorly with the anterior end of esophagus. These "spears" represent an optical section of the buccal capsule with its anterior thickened ring.

e. *Hatching:* While hatching takes place in laboratory cultures in 100 hr at room temperature, it



FIGURES 1–9. Stages in development of the seal hookworm *Uncinaria lucasi*. **1**. Embryonated egg containing third-stage larva, showing two cuticles. **2**. Free-living third-stage larva hatched from egg in laboratory. **3**. Anterior end of parasitic third-stage larva from a pregnant cow. **4**. Posterior end of parasitic third-stage larva from a pregnant cow. **5**. Anterior end of fourth-stage larva from a pup (28 hr). **6**. Posterior end of male fourth-stage larva from a pup (81 hr). **7**. Anterior end of fourth-stage larva from a pup (81 hr). **8**. Posterior end of female fourth-stage larva from a pup (81 hr). **9**. Section of shell of fully developed egg.

is delayed several months on the rookeries. Newly hatched third-stage larvae appear for the first time each season around the end of August or beginning of September, even though eggs have been present since mid-June and the diurnal temperature of the soil ranges from 10 to 12 C.

f. *Free-living third-stage larva:* Upon hatching, third-stage larvae soon lose the outer cuticle resulting from the first molt but retain that of the second (Fig. 2).

Some years, larvae overwinter in the sand in great numbers, whereas in others they do not survive and cannot be recovered until late August. Conditions leading to their destruction or survival are unknown.

Length of 20 larvae 645 to 795 (703.5 SD ± 40.1), width at level of genital primordium 20 to 25 (23.6 SD ± 0.9). Buccal chamber 13 to 14 long, esophagus 170 to 221 long (184.4 SD ± 12.3), bulb 14 to 20 wide (14.8 SD ± 1.9). Distance from anterior end of body: nerve ring 85 to 99 (91.8 SD ± 3.9), excretory pore 102 to 116 (109.3 SD ± 4.3), genital primordium 313 to 354 (331.9 SD ± 10.7). Anus to tip of tail 61 to 78 (69.4 SD ± 4.0); tip of tail to tip of sheath 68 to 99 (83.6 SD ± 23.2).

2. Parasitic stages

a. *Parasitic third-stage larva:* Twenty-five larvae (Figs. 3, 4) recovered from belly blubber and mammary glands of pregnant cows measured 796 to 975 long (880.8 SD ± 48.7) by 31 to 44 wide (36.6 SD ± 3.9) at level of genital primordium; esophagus 214 to 252 long (232.8 SD ± 9.6, bulb 17.0 to 27.2 (21.8 SD ± 2.2). Distance from anterior end: nerve ring 102 to 139 (121.7 SD ± 9.6), excretory pore 129 to 167 (144.2 SD ± 8.7), genital primordium 391 to 602 (522.4 SD ± 47.5). Anus 71 to 102 (84.7 SD ± 8.7) from tip of tail (Fig. 4).

Vacuoles (Fig. 3, v_1), which are the beginning of the provisional buccal capsule of the fourth-stage larva, are usually conspicuous but show various degrees of development.

b. *Parasitic third-stage larva in alimentary canal:* Parasitic third-stage larvae in the milk[1] differ from free-living third-stage larvae in being larger, unsheathed, and partially vacuolated around the buccal capsule. Formation of the provisional buccal capsule is completed in the small intestine, being well advaced by 13 to 15 hr after ingestion.

c. *Fourth-stage larva:* Fourth-stage larvae (Figs. 5–8) appear about 24 hr after ingestion of the parasitic third-stage larvae, as evidenced by a completely formed provisional buccal capsule with four teeth at the base (Figs. 5, 7). The sexes are not completely differentiated at 28 hr but are clearly so at 81 hr with the bursa well developed (Fig. 6) and the tail of the female bluntly pointed (Fig. 8). Larvae 72 hr old showed no sign of vacuoles of the permanent buccal capsule of the fifth stage but these appeared by the fourth day after infection (Fig. 7, v_2). The final molt occurs during the 4th and 5th days after infection.

Measurements were made on three male and three female larvae 81 hr old. Male: Body length 1,500 to 1,545 (1,520 SD ± 22.9), greatest width of body 65 to 68 (65.7 SD ± 1.9); esophagus 360 to 420 long (385 SD ± 31.6) by 45 to 48 (45.9 SD ± 4.7) wide at bulb; distance from anterior end of body to nerve ring 195 to 210 (205 SD ± 8.6), excretory pore 224 to 241 (231.2 SD ± 8.9); distance of anus from posterior end of body 99 to 119 (109.9 SD ± 10.3). Female: Body length 1,530 to 1,830 (1,670 SD ± 150), greatest width 58 to 71 (63.5 SD ± 7.0); esophagus 345 to 405 (370 SD ± 31.2) long by 41 to 51 (46.5 SD ± 5.1), nerve ring 180 to 195 (190 SD ± 8.6), excretory pore 211 to 248 (224.4 SD ± 20.6), from posterior end of body to vulva 570 to 630 (605 SD ± 31.2), to anus 102 to 119 (108.8 SD ± 8.9).

d. *Adult worms:* These were described by Stiles (1901) and later redescribed in greater detail by Baylis (1947) from specimens collected on the Pribilof Islands.

B. Infection of seals from sand

It was earlier postulated by Olsen (1958) that all ages of seals exposed to infested rookeries became infected. It was then thought that larvae entering adult seals were destroyed during migration in the body, whereas those entering pups were able to complete the migration and develop to maturity in the small intestine. This point of view required radical revision in the light of further investigation.

1. Age groups of seals infected

Examination of belly blubber of seals living on the rookeries revealed parasitic third-stage larvae in all age groups (Fig. 10). During the summers of 1961 and 1962 when larvae could not be found in the soil, they did not appear in the blubber of pups until late in August when the eggs began to hatch. Larvae were found during the period throughout the summer in females and males of 1 year of age and older, indicating infection from the previous year when larvae were present.

[1] Since larvae were found in the milk only before and shortly after birth of the pups, it is possible that they are associated with the colostrum. This point was not clarified by tests.

←

Abbreviations: **a**, anus; **b**, bursa; **bc**, buccal capsule; **e**, esophagus; **ep**, excretory pore; **gp**, genital primordium; **i**, intestine; **nr**, nerve ring; **pb**, provisional buccal capsule; **s**, sheath; **t**, teeth; v_1, vacuoles of provisional buccal capsule; v_2, vacuoles of permanent buccal capsule.

FIGURE 10. During the height of the breeding season, hordes of seals return to the same rookeries year after year. When free-living third-stage larvae are present in the sand, intense infection with the tissue phase of hookworms takes place. (Photograph by O. W. Olsen.)

2. Point of entry

It had been demonstrated previously (Olsen, 1958) that free-living third-stage larvae are capable of passing through the hairless plantar skin removed from flippers of dead seals of all age groups.

a. *Percutaneous infection:* Fifteen caesarean pups ranging from 1 to 57 days of age were exposed to infection by placing numerous free-living third-stage larvae on the flippers. Of eight pups examined postmortem, 6, 7, and 8 days after exposure, four were positive with larvae in the belly blubber, whereas no larvae were recovered from seven examined 1, 1, 3, 3, 4, 4, and 9 days, respectively, after exposure.

Grown seals were not used in this experiment because of inability to distinguish experimental larvae from those having entered naturally on the rookeries.

b. *Per os infection:* Of three caesarean pups given doses of several hundred free-living third-stage larvae by means of a stomach tube, two had parasitic third-stage larvae in the belly blubber 8 and 10 days later but the third examined 37 days after exposure failed to show larvae.

From these two experiments, it is evident that free-living third-stage larvae may reach the belly blubber either from the skin or the alimentary canal.

3. Route of migration within the host

Results from attempts to trace the route of migration of larvae from the point of entry to the final location in the belly blubber were not conclusive. It appears that two routes may be taken.

Larvae placed on the distal portion of the flippers were recovered from that point 10 to 144 hr later in four pups, from the proximal portion of the flipper 96 to 144 hr later in two of five pups, in the blood of two of eight pups 17 to 21 hr later, and in the belly blubber 96 to 216 hr after exposure in 4 of 11 pups.

Of three pups given free-living third-stage larvae per os by means of a stomach tube, as mentioned above, two had parasitic third-stage larvae in the belly blubber when examined 8 to 10 days later.

From these observations, it appears that (1) larvae move from the site of entry and occur elsewhere both in the tissues and blood, and (2) that migration takes place from the alimentary canal

FIGURE 11. Newborn pups with placenta still attached are infected with parasitic third-stage larvae with their earliest meal of milk from the mother who harbors the tissue phase. The larvae develop to adults (intestinal phase) in about 2 weeks. (Photograph by E. T. Lyons.)

to the belly blubber. That larvae could wriggle through tissues from the tip of the flipper to the belly blubber in 4 days or from the stomach or intestine to the belly region in 8 days seems unlikely. Utilization of the blood and lymph channels appears more plausible.

4. Point of localization of larvae

Third-stage parasitic larvae locate predominantly in the belly blubber of all seals and in the mammary glands and milk of pregnant cows shortly before parturition and in parous cows for a short time after birth of the pups. A few larvae occur in the subcutaneous fat of other parts of the body and one was recovered from skeletal muscles.

5. Duration of larvae in tissues

Little was discovered regarding the longevity of larvae in the tissues. Pregnant and nonpregnant cows captured at sea en route to the Pribilof Islands from their winter sojourn in the Pacific Ocean harbored parasitic third-stage larvae in the belly blubber. Inasmuch as seals remain at sea for 6 months or more during the winter and spring, these larvae would have been at least that old. That they live somewhat longer than this is highly probable but the extent is unknown.

As pointed out above, adult seals harbored third-stage parasitic larvae in the tissue during years when free-living third-stage larvae could not be found in the soil, and third-stage parasitic larvae were not in the seal pups during the period when larvae were absent from the soil. This condition suggests that the larvae in the grown seals were at least 1 year old, since infection would have occurred the preceding year, at the latest.

If larvae lived for extremely long periods in the tissues, the effects of repeated exposures would be cumulative with vast swarms of them in the tissues of older seals. Such a condition was not observed.

6. Intestinal phase of parasite

Only larvae from the mammary glands ingested with the milk by newborn seals develop to adult worms in the intestine (Fig. 11).

C. Duration postpartum of the larvae in milk

The presence of hookworms of one size only in the intestine of infected pups led to the conclusion that parasitic third-stage larvae are present in the milk for only a short time postpartum. It was not possible to test this point directly, hence an indirect approach was made wherein superinfections were attempted by feeding parasitic third-stage larvae to caesarean pups. If multiple infections developed, as indicated by the presence of worms of different sizes, it would suggest that the pups are susceptible and that the absence of worms of various sizes in the intestine would be due to an absence of larvae in the milk rather than to an acquired resistance resulting from an earlier infection.

Of five caesarean pups 24 hr old given two doses each of parasitic third-stage larvae from

8 to 12 days apart, all became infected and three harbored both adolescent and larval hookworms in the intestine when examined 2 to 4 days after the second infection. The presence of two distinct stages of parasites in the experimental pups and the absence of adult and young worms in naturally infected pups is strong evidence that parasitic third-stage larvae are present in the milk for only a short time postpartum.

D. Experimental infection of pups

Having shown that prenatal infection did not occur in 38 caesarean pups (Lyons and Olsen, 1960), caesarean pups were used in experimental infections. Pups were given parasitic third-stage larvae by mouth from various sources to determine whether they were infective.

1. Larvae in milk from stomach of newborn seal

Milk obtained from the stomach of a newborn seal 2 hr after birth and given by stomach tube to a caesarean pup produced an intestinal infection.

2. Larvae from belly blubber and mammary glands

Of 15 caesarean pups 1 day old given a large number of larvae each in a mixture of mammary glands and surrounding fat from pregnant cows, 13 became infected with worms in the intestine.

Larvae from nonpregnant cows failed to infect five caesarean pups given a larger number of worms each.

3. Infection by nursing recently parturient cows

Of four caesarean pups 1 to 4 days old allowed to nurse recently parturient cows, three became infected. Four of the six cows had infected their own pups previously.

4. Larvae from other than seal cows

Parasitic third-stage larvae obtained from the belly blubber of naturally infected bachelor seals and bachelor sea lions, and from an experimentally infected caesarean seal pup failed to develop to adult worms when introduced by intubation into the stomach of caesarean seal pups.

E. Prepatent period

The prepatent periods in four pups born in cages and infected by nursing their dams were 12, 13, 14, and 15 days after birth as indicated by the appearance of eggs in the feces. In one caesarean pup infected experimentally, eggs appeared in the feces 13 days after exposure.

F. Incidence and duration of adult worms in intestine

Examination by one of us (O. W. O.) of 553 dead pups in August, 1955, showed approximately 66% infected; another 250 checked between 22 July and 21 August, 5 years later (Lyons and Olsen, 1960), revealed infections ranging from 55 to 85% on various rookeries. Of 50 pups killed during late August of the same year, 44, or 88%, were infected.

Observations over several years indicated that the percentage of infected pups in the population declined in the fall. This condition might be expected when seals 1 year of age and over are free of adult hookworms, as had been demonstrated to be the case (Olsen, 1958). In the summer of 1961, ten lots of ten pups each were examined between 18 August and 27 October to ascertain the nature of the decline. On 18 August, seven of ten pups harbored adult hookworms in the intestine; on 1 and 8 September, six and two, respectively, were infected; and at weekly intervals thereafter until 27 October all (70 pups) were negative.

Examination of seals, including rookery pups, pregnant and parous cows, bachelors, and bulls, and grown sea lions were made to determine the incidence of infection with parasitic third-stage larvae in the tissues.

1. Rookery pups

During the years when larvae did not overwinter in the soil, pups did not become infected until August when larvae began to appear in the soil from hatching eggs. On 11 August 1961, the first infection in 90 pups examined up to that time appeared when larvae were found in the fat of one individual. There was a progressive increase until 22 September when all of ten examined were positive. A similar situation prevailed in 1962 when a total of 54 pups examined at weekly intervals, beginning 23 June, revealed the first infections on 18 August when four of five animals were positive.

2. Cows

Of 26 pregnant and one nonpregnant cows captured at sea en route to the Pribilof Islands after having spent the winter in the Pacific Ocean, 20 were positive.

Of 25 pregnant cows caught on the Pribilof Islands and examined prior to parturition, 21 were infected. Of eight examined only from milk stripped from the teats, seven were infected.

Thirty-six parous cows from rookeries were examined by checking the belly blubber and mammary glands; 28 harbored larvae. Blubber from the

backs of three of five additional cows and the neck of each of two others contained larvae, showing that they go to parts other than belly blubber. Eight additional cows were milked but no larvae were found.

3. Other categories of seals

Five of seven yearlings (sex unknown) examined were positive. Of the males, 8 of 13 bachelors and all of 3 large bulls harbored larvae.

4. Sea lions

All of four large males examined were infected.

5. All classes of seals

Each of the parts of the body listed below taken from a number of pups, bachelors, cows, and bulls was examined for larvae. The parts included bone marrow, blood, kidneys, lungs, flippers, spleen, liver, skeletal muscles, and uterus. Larvae were found only in the flippers of two rookery pups and the skeletal muscles of one nonpregnant cow.

H. Continuance postpartum of larvae in milk

That larvae persist in the milk postpartum seemed unlikely *a priori* on the basis of early observations on many pups by one of us (O. W. O.) who found only adult hookworms in dead or sick pups. Had larvae migrated continually from the fat to the milk and been available to the pups throughout the nursing period, there should have been worms of various stages of development in the intestine at all times. This, however, was not the case. Milk examined from the stomachs of ten large rookery pups that had nursed cows just back from a foraging trip at sea was negative for hookworm larvae. Had larvae been getting into the milk from the tissues at this time, it is likely that the period at sea, which is usually a week or thereabouts, would have been long enough for them to accumulate in the milk cisterns with subsequent transfer to the pups where they could have been found.

DISCUSSION

Prior to the study of the life cycle of *Uncinaria lucasi* by Olsen (1958), and during the early part of his investigations, it was believed that the biology would be similar to that known for species of hookworms occurring in humans and other animals, wherein third-stage larvae enter the host through the skin and migrate via the blood vessels, heart, lungs, and trachea to the intestine where final development to maturity occurs. In attempts to complete the life cycle, Olsen (1958) failed to infect seal pups and produce adult hookworms when larvae were placed on the flippers, in the stomach, or elsewhere in or on the body.

Accumulated information on the biology of *U. lucasi* led to the conviction that its life cycle is different from the conventional type seen in other species of hookworms. The reasons for this view are outlined elsewhere in this paper. Briefly, they centered around the fact that pups 2 weeks of age and older harbored only adult worms in the intestine, not a series of sizes ranging from parasitic third-stage larvae to adults, as should be expected if infection were occurring continuously by way of the skin, and that pups bore a high incidence of infection with numerous worms even when larvae could not be demonstrated in the sand of the rookeries. From these and other observations, it was apparent that infection must occur at one time only and from a source other than the rookery. It appeared that only the mother could serve as the reservoir from which the infection must come.

These observations suggested that infection possibly occurred prenatally as reported for *Ancylostoma caninum* by Foster (1932) and *Toxocara canis* by Sprent (1954).

Tests for prenatal infection included the examination of tissues of fetal and caesarean pups for larvae and of holding live caesarean pups in cages sufficiently long to allow any larvae present in the body to migrate to the intestine and grow to a size easily detected. About 40 pups were examined by these methods the 1st year without finding evidence of infection. Inasmuch as 90% or more of the pups born on the rookeries were infected naturally, infections should have been expected in about 36 of those examined if prenatal infection occurs.

Since prenatal infection could not be proved, further studies on postnatal infection were undertaken. These involved placing pregnant cows in individual cages where their young were born on areas never occupied by seals and therefore free of hookworm larvae. Any infections occurring in pups born under these conditions would have to be from the mothers. Having noted that well-fed pups rather than starving ones were infected, Lucas

(1899) suggested that infection might result from larvae obtained from the mothers' fur by nursing pups. This suggestion was considered unlikely in the light of Olsen's (1958) failure to infect pups by placing larvae directly in the stomach by intubation.

Nine of ten pups born in cages on uncontaminated soil harbored hookworms in the intestine at an early age. This condition demonstrated that infection was associated with the mother and not acquired from the soil. Although the cows had not been washed to remove any larvae that might have been on the fur of the belly, this source of infection appeared unlikely for reasons stated above. Moreover, if this were the source of larvae, various sizes of worms might be expected in the intestine of rookery pups resulting from repeated exposures under natural conditions. The possibility, however, of pups being susceptible to infection during only the first few hours of postnatal life was considered, even though it seemed unlikely. Such a condition would explain the presence of one size of worms in the intestine rather than a graded series consisting of third- and fourth-stage larvae, and adolescent and adult worms, as might otherwise be expected.

Examination of pups soon after birth in the maternity cages disclosed larval nematodes in the alimentary canal and always in association with milk. Harking back to the concept of Lucas that larvae might be acquired from the fur while nursing, this suggested another alternative, namely, that larvae might be passed from the mother to her young pup in the milk, a concept that had been considered previously but rejected as improbable. Examination of the belly blubber, mammary glands, and milk of full-term pregnant and recently parturient cows revealed numerous larvae similar to those found in the stomachs of newborn pups immediately following their first meal of milk.

Critical examination of the larvae in the milk disclosed them to be larger and slightly more advanced in development than the free-living stage in the soil, yet still in the third stage. Hence two types of third-stage larvae were recognized: a preparasitic free-living stage in the soil and a parasitic one in the blubber, mammary glands, and milk of the mother.

Observations and experiments established the fact that larvae persist in the milk for only a short time postpartum. The mode of transmission of the larvae to the pups and the short time they occur in the milk explains (1) the presence of only one size of worms in the intestine, (2) infection of pups on rookeries where larvae could not be found, and (3) the presence of worms in seals born on boulders from which all larvae would have been washed by the sea during the absence of the seals.

The number of hookworms present in a seal pup is dependent upon the number in the milk at the time of parturition. The maximum number observed per pup was 1,500. The stimulus or stimuli prompting the parasitic third-stage larvae to migrate prepartum from the tissues to the milk cisterns is unknown. Webster (1958) postulated that larvae of *Toxocara canis* in the tissues of bitches are stimulated to migrate by certain hormones that occur during pregnancy. In support of the pregnancy hormone concept, it was noted that in fur seals only larvae from pregnant and recently parturient cows were infective, whereas those from nonpregnant cows, males, and pups were not infective.

Third-stage larvae survive the winter on the rookeries some years and not others. When survival occurs, the larvae gradually decline in number during the course of the summer and disappear completely about the first of August (Olsen, 1958).

Eggs passed onto the rookeries throughout the summer do not hatch until late in August or early in September even though the temperature of the soil appears to be favorable for complete development and hatching before this time. In years when larvae do not overwinter, these late-appearing larvae are the only ones available to infect adults and pups, producing the tissue phase in them. In years when larvae overwinter, they are available, often in great numbers, and infect all seals throughout the summer.

Accumulation of great numbers of larvae in the females would present the hazard of lethal doses to all pups. Possibly summers in which extremely high mortality of pups occurs are preceded by winters a year prior when tremendous numbers of larvae survive and enter the female seals in hordes to be passed to the nursing pups the following summer. It

was just such a set of circumstances as these when the maximum number of 1,500 adult hookworms was found in two pups (Olsen, 1958) and during years when great numbers of pups were dying.

The life cycle of *U. lucasi* has three parts. They are: (1) the intestinal phase consisting of adult worms in young pups but not in older seals; (2) the free-living phase with eggs and third-stage larvae in the soil; and (3) the tissue phase in which third-stage parasitic larvae occur in the fat of the belly region, mammary glands, and milk.

The unique nature of the life cycle of *U. lucasi* undoubtedly is related to the evolution of its host from adaptation to a terrestrial habitat to one including both terrestrial and marine phases wherein approximately half of each year is spent wholly at sea and the other half on both land and in the sea. Chief adaptations of the parasite are the ability of infective larvae to reside in the tissues, thereby escaping the hazards of survival in the soil during the absence of the seals in the winter when the climate is most rigorous and its effect most lethal, and their transmission to the newborn seals through the milk. By utilizing the milk as a medium of transferring the infective larvae, infection of new seals and perpetuation of the parasite are assured with a high degree of efficiency.

While obviously adapted to the harsh terms of the seals' life, it is doubtful that this type of life cycle is more effective than what might be considered the ancestral one. While it does afford an effective means of transmitting the parasites to the newborn seals, it may be less so than the ancestral type. True, it provides a highly efficient means of perpetuating the parasite by protecting the third-stage larvae against hazardous conditions on the rookeries through storing them in the bodies of females. However, the ancestral type of life cycle in a host having gregarious and homing instincts, where protective harborage of adult worms would occur in the intestine of all age groups of both sexes and infection of new hosts would take place by free-living larvae entering through the flippers and migrating in the blood vessels, heart, lungs, and trachea to the intestine, would appear to be more effective utilization of the reproductive potential of the parasite in its own behalf.

It is not clear why adult seals do not harbor hookworms in the intestine in the same manner as the pups.

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[Reprinted from Publ. Institute of Marine Science, Texas, Vol. 10, June, 1965]

An Annotated Checklist of the Fishes of the Galveston Bay System, Texas[1]

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Abstract

This checklist includes fishes collected from Galveston Bay, Texas, in the course of regularly scheduled sampling operations by the Bureau of Commercial Fisheries during the years 1961–64. All other species known to occur in this bay system are also listed. The annotations, although incomplete in many instances, indicate the relative abundance of each species, as well as its distribution with respect to area, season, and salinity. Such information is based on observations by the author and those recorded in the literature. In all, 162 species represented by 122 genera and 66 families are listed.

Introduction

This checklist is intended to expand present knowledge of the composition and distribution of the first fauna inhabiting Gulf coast estuaries and lagoons. Hoese (1958) noted the need for centralized information of this type for fishes in the Gulf of Mexico, and a similar need has become evident in the case of fish occurring in estuaries and lagoons of the Gulf coast. Much of the existing information on this subject is either recorded in mimeographed reports having limited distribution or is scattered throughout a variety of journals. To provide a more comprehensive listing, I have combined records from all other sources with information (1) furnished by personnel of the Texas Parks and Wildlife Department, and (2) collected over a 4-year period in the Galveston Bay system by personnel of the Bureau of Commercial Fisheries.

Previous Literature

Jordan and Gilbert (1883) presented the first scientific listing of fishes from the Galveston area and included four species from the bay system proper. In 1894, Evermann and Kendall contributed additional species listings, as did Fowler (1915) and Baughman (1950a, 1950b). But it was not until Reid's studies (1955a, 1955b, 1956, 1957) in East Bay that an extensive survey of the fish fauna was presented. Rather elaborate studies have since been conducted by Chambers and Sparks (1959) in the upper (estuarine) portions of the Houston Ship Channel; by Hoese (1959a, 1959b, 1959c) in East and West Bays, the passes, and near the Galveston Jetties; by Renfro (1959a, 1959b) in Upper Galveston and Trinity Bays; by Arnold, Wheeler, and Baxter (1960) in East Lagoon; by Shidler (1960) throughout the bay system; by Pullen (1960, 1961, 1962) in Upper Galveston and Trinity Bays; and by Chin (1961) in Clear Lake.

[1] Contribution No. 198, Bureau of Commercial Fisheries, Galveston, Texas.

Description of the Area

The Galveston Bay system is bounded from east to west on its seaward side by the Bolivar Peninsula, Galveston Island, and Follets Island, and is connected with the Gulf by Rollover Pass, Bolivar Roads, and San Luis Pass (Fig. 1). Fresh water enters by way of two major river systems: the Trinity which empties into Trinity Bay and the San Jacinto which empties into the Houston Ship Channel and thence into Upper Gal-

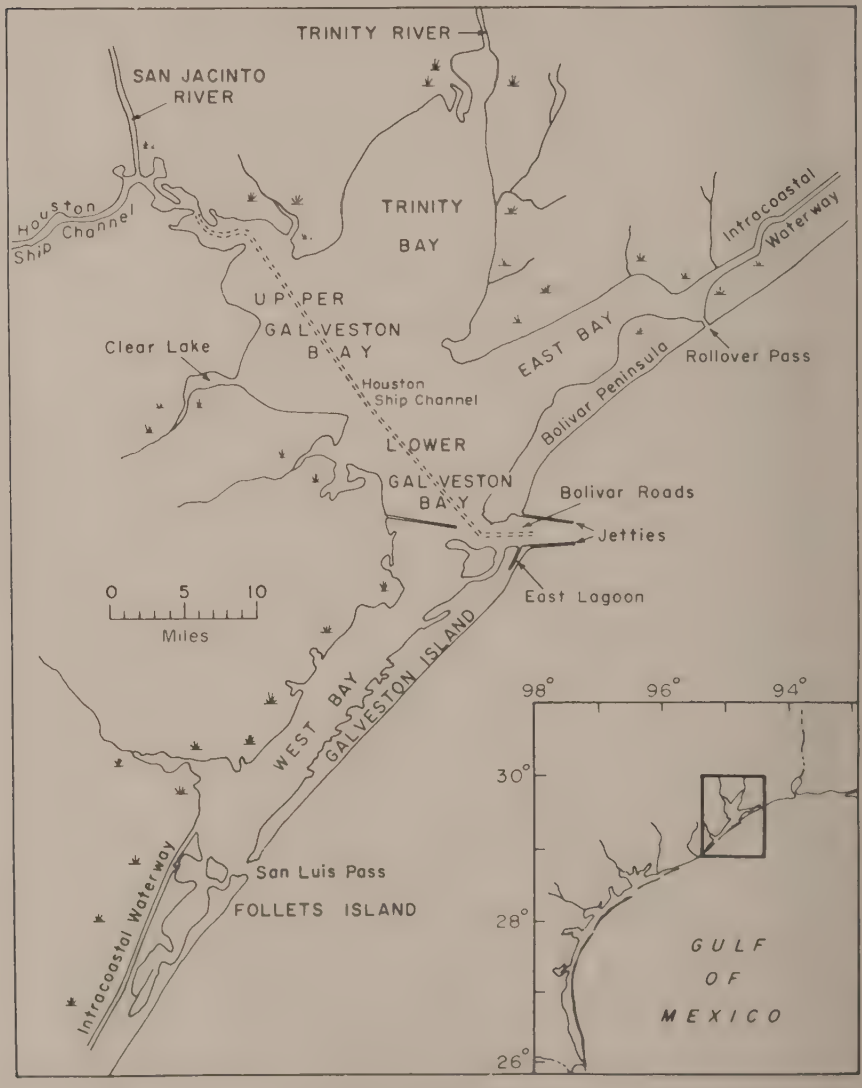

FIG. 1. Map of Galveston Bay.

veston Bay. Additional fresh water is contributed by numerous bayous and creeks as well as by the Intracoastal Waterway which transports runoff from peripheral marsh areas. Comprising an area of some 525 square miles, the system is composed of East Bay, West Bay, Upper and Lower Galveston Bays, and Trinity Bay, along with sundry secondary bays and lakes. The seaward limits of the system with respect to the species included in the following list were arbitrarily placed just inside the passes and jetties. The inland limits were set at the mouths of the San Jacinto and Trinity Rivers and at the east and west entrances of the Intracoastal Waterway. Observations in the near vicinity of the mouths of the numerous bayous and creeks are included.

Presentation of Species

The annotations, although incomplete in many instances, are intended to describe the relative abundance of each species as well as its distribution with respect to area, season, and salinity. Those species collected and/or identified by Bureau of Commercial Fisheries personnel during the years 1961–64 are designated with an asterisk (*). References following annotations include those studies which have contributed to the knowledge of the indicated species. It should be understood that many of the fishes inhabiting the inshore waters of the Gulf of Mexico and the fresh-water rivers and streams which empty into them are only occasional migrants into the bays. No attempt is made to include unreported but likely occurring forms or species whose location has been listed as "Galveston" with no specific reference to the bay system itself.

The fish species are listed according to the American Fisheries Society's "List of Common and Scientific Names of Fishes From the United States and Canada" (Special Publication No. 2, 2nd Ed., 1960). If more recent taxonomic revisions are available, however, the latest nomenclature is used. In all, 162 species represented by 122 genera and 66 families are included. Of these species, 115 were identified from material made available to the author. Information on the remaining 47 was obtained from published reports or from unpublished records of the Texas Parks and Wildlife Department.

Four arbitrary categories are used to indicate relative abundance: rare, uncommon, common, and abundant. A real distribution is described on the basis of seasons and salinity. Where appropriate, self-explantory hydrographic connotations are also included.

The criteria which were used to describe the salinity characteristics of the Galveston Bay system are: extremely low (0–5 ppt), low (5–10 ppt), moderate (10–20 ppt), and high (20–35 ppt). Generally, under average river-flow conditions, extremely low salinity water is restricted to the marshes and bayous of the upper bays and to areas near the mouths of the rivers. Low salinity conditions are normally observed in the upper portions of Trinity, Upper Galveston, and East Bays; whereas, moderate salinity water is usually found in the lower regions of these bays as well as in the greater part of West Bay and the upper part of Lower Galveston Bay. The waters in and immediately adjacent to the jetties and passes normally fall into the high salinity range. A wedge of high salinity water consistently penetrates the bay at the bottom of the Houston Ship Channel, being observed on occasion some 20 nautical miles up the Channel from the Gulf.

Annotated List

CLASS CHONDRICHTHYES—Cartilaginous Fishes

ORDER SQUALIFORMES (Selachii)

Family Carcharhinidae—Requiem sharks

Carcharhinus leucas (Muller and Henle)—Bull shark

Rare, an occasional summer resident in high salinity waters. Renfro (1959a); Pullen (1960, 1962).

C. limbatus (Muller and Henle)—Blacktip shark

Rare, an occasional summer resident in high salinity waters. Reid (1955a, 1955b, 1956, 1957).

Scoliodon terraenovae (Richardson)—Atlantic sharpnose shark

Rare, one specimen taken from West Bay in the summer of 1961 was identified by biologists of the Texas Game and Fish Commission (personal communication).

Family Sphyrnidae—Hammerhead sharks

Sphyrna lewini (Griffith)—Scalloped hammerhead shark*

Rare, a summer migrant usually present in high salinity waters.

S. tiburo (Linnaeus)—Bonnethead*

Uncommon, a summer migrant usually present in high salinity waters.

ORDER RAJIFORMES (BATOIDEI)

Family Pristidae—Sawfishes

Pristis pectinatus Latham—Smalltooth sawfish*

Rare, both young and adults have been caught in waters of high salinity.

Family Rajidae—Skates

Raja texana Chandler—Roundell skate*

Rare, one specimen was collected in East Bay in the summer of 1963.

Family Dasyatidae—Stingrays

Dasyatis americana Hildebrand and Schroeder—Southern stingray*

Uncommon in this bay system.

D. sabina (LeSueur)—Atlantic stingray*

This is the common stingray of the area and is abundant during the spring and summer in both moderate and high salinity waters. Reid (1955a, 1955b, 1956, 1957); Hoese (1959a); Renfro (1959b); Shidler (1960); Pullen (1960, 1962).

D. sayi (LeSueur)—Bluntnose stingray *

Rare, one specimen was collected in East Bay in the spring of 1963.

Gymnura micrura (Bloch and Schneider)—Smooth butterfly ray*

Rare, apparently restricted to high salinity waters. Hoese (1959b).

Family Myliobatidae—Eagle rays

Aetobatus narinari (Euphrasen)—Spotted eagle ray*

Rare, collected from West Bay in August 1964 by a local fisherman.

Rhinoptera bonasus (Mitchill)—Cownose ray

Although uncommon during most of the year, there is evidence that large schools of the cownose ray spawn in the bay system in late summer. Pullen (1960, 1962).

CLASS OSTEICHTHYES—Bony Fishes

ORDER ACIPENSERIFORMES (CHONDROSTEI)

Family Polyodontidae—Paddlefishes

Polyodon spathula (Walbaum)—Paddlefish*

Rare, found near shore between the Galveston jetties in 1960 by a local resident. The fish, a fresh-water species, was alive but very sluggish when captured.

ODRER SEMIONOTIFORMES (PROTOSPONDYLI AND GINGLYMODI)

Family Lepisosteidae—Gars

Lepisosteus oculatus (Winchell)—Spotted gar*

Common during all seasons, inhabiting extremely low to low salinity waters of the bayous and marshes. Reid (1955b, 1956, 1957) as *L. productus* Cope; Chambers and Sparks (1959) as *L. productus* (Cope); Chin (1961).

L. osseus (Linnaeus)—Longnose gar*

Uncommon, accasionally entering the extremely low to low salinity waters of the bayous and marshes. Renfro (1959a, 1959b); Pullen (1960, 1962); Renfro (1963).

L. platostomus Rafinesque—Shortnose gar

Rare, predominantly a fresh-water species. Chambers and Sparks (1959).

L. spatula (Lacépède)—Alligator gar*

Common from spring through fall in waters of low to moderate salinity. Baughman (1950a); Reid (1956, 1957); Chambers and Sparks (1959); Hoese (1959b); Renfro (1959a, 1959b); Arnold, Wheeler, and Baxter (1960); Pullen (1960, 1962); Chin (1961).

ORDER CLUPEIFORMES (ISOSPONDYLI)

Family Elopidae—Tarpons

Elops saurus Linnaeus—Ladyfish*

Common during the summer in moderate to high salinity waters. Fowler (1945); Reid (1955a, 1955b, 1956, 1957); Renfro (1959a); Arnold, Wheeler, and Baxter (1960); Pullen (1960, 1962).

Megalops atlantica Valenciennes—Tarpon*

Uncommon, during the summer schools of tarpon occasionally enter high salinity waters. Baughman (1950a) as *Tarpon atlanticus* Cuvier and Valenciennes.

Family Albulidae—Bonefishes

Albula vulpes (Linnaeus)—Bonefish

Baughman (1950a) reports a record of this species from Galveston Bay, but as it is a leptocephalid, he presumes it might have been *Elops saurus* Linnaeus.

Family Clupeidae—Herrings

Alosa charysochloris (Rafinesque)—Skipjack herring*

Uncommon, this fresh-water species occasionally frequents extremely low to low salinity waters. Pullen (1962).

Brevoortia gunteri Hildebrand—Finescale menhaden*

Uncommon, a marine species seldom found in the bays.

B. patronus Goode—Largescale menhaden*

Abundant, found year round throughout the bay system. Fowler (1945) as

B. tyranus patronus Goode: Reid (1955a, 1955b, 1956, 1957); Chambers and Sparks (1959); Hoese (1959b); Renfro (1959a, 1959b); Arnold, Wheeler and Baxter (1960); Pullen (1960, 1961, 1962); Shidler (1960); Chin (1961); Renfro (1963); Stevens (1963b).

Dorosoma cepedianum (LeSueur)—Gizzard shad*

Common from spring through fall, residing predominantly in extremely low to low salinity waters. Jordan and Gilbert (1883): Reid (1955a, 1955b, 1956, 1957); Chambers and Sparks (1959); Renfro (1959a, 1959b); Arnold, Wheeler and Baxter (1960); Chin (1961); Pullen (1960, 1961, 1962).

D. petenese (Günther)—Threadfin shad*

Common in the summer, fall, and winter in extremely low to moderate salinity waters. Fowler (1945) as *Signalosa patensis atchafalayae* Evermann and Kendall; Reid (1955a, 1955b, 1956, 1957) as *S. petenesis* Günther; Chambers and Sparks (1959); Renfro (1959a); Chin (1961); Pullen (1960, 1961, 1962).

Harengula pensacolae Goode and Bean—Scaled sardine*

Common during late summer and early fall near the jetties and passes. Reid (1955b, 1956, 1957) as *H. p. pensacolae* Goode and Bean: Arnold, Wheeler and Baxton (1960).

Opisthonema oglinum (LeSueur)—Atlantic threadfin herring*

Uncommon, occasionally present in waters of high salinity. Arnold, Wheeler and Baxter (1960).

Sardinella anchovia Valenciennes—Spanish sardine

Rare. Fowler (1945).

Family Engraulidae—Anchovies

Anchoa hepsetus (Linnaeus)—Striped anchovy*

Uncommon, occasionally present in waters of high salinity. Reid (1955a, 1955b, 1956, 1957); Hoese (1959b); Renfro (1959a); Arnold, Wheeler and Baxter (1960); Pullen (1960, 1962).

A. mitchilli (Valenciennes)—Bay anchovy*

Abundant, found in large numbers during all seasons throughout the bay system. Jordan and Gilbert (1883) as *Stolephorus mitchilli* (Cuvier and Valenciennes); Fowler (1945) as *A. m. mitchilli* (Valenciennes); Reid (1955a, 1955b, 1956, 1957) as *A. m. diaphana* Hildebrand; Chambers and Sparks (1959) as *A. mitchilli* Hildebrand; Hoese (1959b); Renfro (1959a, 1959b); Arnold, Wheeler and Baxter (1960) as *A. m. diaphana* (Cuvier and Valenciennes); Pullen (1960) as *A. m. diaphana* Hildebrand; Chin (1961) as *A. m. diaphana* Hildebrand; Pullen (1961, 1962); Renfro (1963); Stevens (1963b).

ORDER MYCTOPHIFORMES (INIOMI)

Family Syndontidae—Lizardfishes

Synodus foetens (Linnaeus)—Inshore lizardfish*

Common, found during spring, summer, and fall in high salinity waters. Fowler (1945); Reid (1955a, 1955b, 1956, 1957); Hoese (1959b); Renfro (1959a); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1961, 1962).

ORDER CYPRINFORMES (OSTARIOPHYSI)

Family Cyprinidae—Minnows and carps

Campostoma anomalum (Rafinesque)—Stoneroller
Rare. Fowler (1945).

Cyprinus carpio Linnaeus—Carp*
Rare, found in extremely low salinity water near the mouths of the rivers and bayous. Chambers and Sparks (1959); Pullen (1960, 1962).

Notropis sp.—Shiner
Rare, predominantly a fresh-water species. Pullen (1962).

Family Catostomidae—Suckers

Carpiodes carpio (Rafinesque)—River carpsucker*
Rare, found in waters of low salinity near the mouths of the rivers and bayous. Renfro (1959a, 1959c).

Ictiobus bubalus (Rafinesque)—Smallmouth buffalo*
Rare, restricted to waters of low salinity near the mouths of the rivers and bayous. Chambers and Sparks (1959); Pullen (1960, 1962).

Family Ariidae—Sea Catfishes

Bagre marinus (Mitchill)—Gafftopsail catfish*
Abundant from summer through fall in low to high salinity waters. Fowler (1945) as *Ailurichthys marinus* (Mitchill); Reid (1955a, 1955b, 1956, 1957); Chambers and Sparks (1959); Renfro (1959a, 1959b); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1962).

Galeichthys felis (Linnaeus)—Sea catfish*
Abundant from spring through fall in moderate to high salinity waters. Fowler (1945) as *Trachysurus felis* (Linnaeus); Reid (1955a, 1955b, 1956, 1957); Chambers and Sparks (1959); Renfro (1959a, 1959b); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1961, 1962).

Family Ictaluridae—Freshwater catfishes

Ictalurus furcatus (LeSueur)—Blue catfish*
Rare, found in low salinity water near the mouths of the rivers and bayous. Renfro (1959a, 1959c); Pullen (1960, 1961, 1962) as *I. f. furcatus* (LeSueur).

I. melas (Rafinesque)—Black bullhead
Rare, found in low salinity water near the mouths of the rivers and bayous. Chambers and Sparks (1959) as *Ameirus melas* (Girard); Renfro (1959a); Pullen (1960, 1962) as *Amerius mela* Rafinesque.

I. natalis (LeSueur)—Yellow bullhead
Rare, found in low salinity water near the mouths of the rivers and bayous. Pullen (1962).

I. punctatus (Rafinesque)—Channel catfish*
Rare, found in low salinity water near the mouths of the rivers and bayous. Renfro (1959a); Pullen (1960) as *I. p. punctatus* (Rafinesque); Pullen (1962).

ORDER ANGUILLIFORMES (APODES)

Family Anguillidae—Freshwater eel

Anguilla rostrata (LeSueur)—American eel.

Rare. Reported near the mouth of the Trinity River in data collected for a class project by the Department of Wildlife Management. Texas A & M University.

Family Muraenidae—Morays

Gymnothorax moringa (Cuvier)—Spotted moray*

Rare. found near the jetties and passes. Arnold. Wheeler and Baxter (1960) as *G. ocellatus* Agassiz.

Family Ophichthidae—Snake Eels

Myrophis punctatus Lütken—Speckled worm eel*

Common. This is the most abundant eel in the bay system although not collected in large numbers, it is distributed throughout the bay. Reid (1955b, 1956, 1957); Renfro (1959a, 1959b, 1963); Arnold, Wheeler and Baxter (1960); Chin (1961); Pullen (1960, 1962).

Mystriophis mordax (Poey)—Snapper eel

Rare, apparently restricted to high salinity waters. Reid (1957); Arnold, Wheeler and Baxter (1960).

Ophichthus gomesi (Castelnau)—Shrimp eel*

Uncommon, found occasionally in moderate to high salinity waters. Renfro (1959a).

ORDER BELONIFORMES (SYNENTOGNATHI)

Family Belonidae—Needlefishes

Strongylura marina (Walbaum)—Atlantic needlefish*

Common in waters of high salinity. Chambers and Sparks (1959): Renfro (1959a); Arnold, Wheeler and Baxter (1960); Pullen (1960, 1962).

Family Hemiramphidae—Halfbeaks

Hyporhamphus unifasciatus (Ranzani)—Halfbeak

Uncommon, found occasionally from spring through summer near the jetties. Arnold, Wheeler and Baxter (1960).

Family Exocoetidae—Flyingfishes

Prognichthys rondeleti (Valenciennes)—Blackwing flyingfish

Rare. Baughman (1950a) as *Danichthys rondeletii* (Cuvier and Valenciennes). Biologists of the Texas Parks and Wildlife Department collected this species in Upper Galveston Bay in the spring of 1961 (personal communication).

ORDER CYPRINODONTIFORMES (MICROYPRIŃI)

Family Cyprinodontidae—Killifishes

Adinia xenica (Jordan and Gilbert)—Diamond killifish*

Uncommon, but apparently distributed throughout the bay system in shallow water grass flats. Reid (1956): Simpson and Gunter (1956) as *A. multifasciata* Girard: Reid (1957): Renfro (1959a): Arnold, Wheeler and Baxter (1960); Pullen (1960, 1962).

Cyprinodon variegatus Lacépède—Sheepshead minnow*

Common in shallow waters throughout the bay system. Evermann and Kendall (1894); Reid (1955a, 1955b, 1956) as *C. v. variegatus* Lacépède; Simpson and Gunter (1956); Reid (1957) as *C. v. variegatus*; Chambers and Sparks (1959); Arnold, Wheeler and Baxter (1960) as *C. v. variegatus* Lacépède; Shidler (1960); Chin (1961); Pullen (1960, 1961, 1962).

Fundulus chrysotus (Günther)—Golden topminnow

Rare, apparently restricted to waters of extremely low salinity. Baughmann (1950a).

F. grandis Baird and Girard—Gulf killifish*

Common year round in shallow water areas. Evermann and Kendall (1894) as *F. pallidus* Evermann; Fowler (1945) as *F. heteroclitus grandis* Baird and Girard; Reid (1955a, 1955b, 1956) as *F. g. grandis* Baird and Girard; Simpson and Gunter (1956); Reid (1957) as *F. g. grandis* Baird and Girard; Chambers and Sparks (1959); Renfro (1959a); Arnold, Wheeler and Baxter (1960); Pullen (1960, 1962).

F. jenkinsi (Evermann)—Saltmarsh topminnow

Rare, apparently restricted to extremely low to moderate salinity waters near the mouths of the bayous and creeks. Evermann and Kendall (1894) as *Zygonectes jenkinsi* Evermann; Simpson and Gunter (1956).

F. pulvereus (Evermann)—Bayou killifish

Rare, apparently restricted to extremely low to moderate salinity waters near the mouths of the bayous and creeks. Gunter and Knapp (1951); Simpson and Gunter (1956); Pullen (1962).

F. similis (Baird and Girard)—Longnose killifish*

Common throughout the year in shallow waters. Fowler (1945); Reid (1955b, 1956, 1957); Simpson and Gunter (1956); Chambers and Sparks (1959); Renfro (1959a); Arnold, Wheeler and Baxter (1960); Chin (1961); Pullen (1960, 1962).

Lucania parva (Baird and Girard)—Rainwater killifish*

Common to the waters of shallows and flats. Simpson and Gunter (1956); Pullen (1960, 1962).

Family Poeciliidae—Livebearers

Gambusia affinis (Baird and Girard)—Mosquitofish

Common in waters near shore and in marshy flats. Simpson and Gunter (1956); Renfro (1959a, 1959b); Pullen (1960, 1962).

Mollienesia latipinna LeSueur—Sailfin molly*

Common year round in the waters of shallows and flats. Reid (1955b, 1956); Simpson and Gunter (1956); Reid (1957); Renfro (1959a, 1959b); Arnold, Wheeler and Baxter (1960); Pullen (1960, 1961, 1962).

ORDER GADIFORMES (ANACANTHINI)

Family Gadidae—Hakes

Urophycis floridanus (Bean and Dresel)—Southern hake*

Uncommon, found in small numbers during the spring, fall, and winter. Fowler (1945); Chambers and Sparks (1959); Hoese (1959b); Renfro (1959a); Pullen (1960); Chin (1961).

ORDER GASTEROSTEIFORMES (THORACOSTEI + HEMIBRANCHII + LOPHOBRANCHII + SOLENICHTHYES)

Family Syngnathidae—Pipefishes and seahorses

Hippocampus erectus Perry—Spotted seahorse*

Rare, found in waters of high salinity near floating seaweed and in shallow grass flats.

H. zosterae Jordan and Gilbert—Dwarf seahorse*

Rare, found in waters of high salinity near floating seaweed and in shallow grass flats.

Syngnathus floridae (Jordan and Gilbert)—Dusky pipefish*

Rare, inhabiting high salinity waters of grassy flats. Hoese (1959b); Renfro (1959a); Pullen (1960, 1962).

S. louisianae Günther—Chain pipefish

Rare, reported from East Bay. Reid (1955a, 1955b, 1956, 1957).

S. scovelli (Evermann and Kendall)—Gulf pipefish*

Common in moderate to high salinity waters in areas of vegetation. Hoese (1959b); Renfro (1959a); Chin (1961); Pullen (1962).

ORDER PERCOPSIFORMES (SALMOPERCAE)

Family Aphredoderidae—Pirate perches

Aphredoderus sayanus (Gilliams)—Pirate perch

Rare, predominantly a fresh-water species. Pullen (1960, 1962) as *A. s. gibbosus* (LeSueur).

ORDER PERCIFORMES (PERCOMORPHI, ACANTHOPTERYGII)

Family Serranidae—Sea basses

Centropristes philadelphicus (Linnaeus)—Rock sea bass*

Rare, found in waters of high salinity. Hoese (1959b); Renfro (1959a); Pullen (1960, 1961, 1962).

Epinephelus itajara (Lichtenstein)—Jewfish

Rare, found predominantly near the jetties. Hoese (1959a) as *Promicrops itiaria* (Lichtenstein).

E. nigritus (Holbrook)—Warsaw grouper*

Rare, collected in West Bay in January 1963 by a local fisherman.

Roccus chrysops (Rafinesque)—White bass

Rare, predominantly a fresh-water species. Chambers and Sparks (1959).

R. mississippiensis (Jordan and Eigenmann)—Yellow bass

Rare, a fresh-water species which occasionally ventures into low salinity waters. Chambers and Sparks (1959); Renfro (1959a, 1959c).

Family Lobotidae—Tripletails

Lobotes surinamensis (Bloch)—Tripletail

Uncommon. Reid (1955a, 1955b, 1956, 1957); Pullen (1962).

Family Lutjanidae—Snappers

Lutjanus apodus (Walbaum)—Schoolmaster

Rare, collected in 1963 in East Bay by personnel of the Texas Parks and Wildlife Department (personal communication).

L. griseus (Linnaeus)—Gray snapper

Rare, reported from West Bay in 1963 by personnel of the Texas Parks and Wildlife Department (personal communication).

L. synagris (Linnaeus)—Lane snapper*

Uncommon, frequenting waters of high salinity. Arnold, Wheeler and Baxter (1960).

Family Centrarchidae—Sunfishes

Chaenobryttus gulosus (Cuvier)—Warmouth*

Rare, a fresh-water species which occasionally ventures into low salinity waters during periods of fresh-water discharge from the rivers and bayous. Chambers and Sparks (1959); Renfro (1959a); Pullen (1960, 1962).

Lepomis macrochirus Rafinesque—Bluegill*

Rare, a fresh-water species which occasionally ventures into low salinity waters during periods of fresh-water discharge from the rivers and bayous. Pullen (1962).

L. microlophus (Günther)—Redear sunfish

Rare, a fresh-water species which occasionally ventures into low salinity waters during periods of fresh-water discharge from the rivers and bayous. Chambers and Sparks (1959); Pullen (1960, 1962).

Pomoxis annularis Rafinesque—White crappie*

Rare, a fresh-water species which occasionally ventures into low salinity waters during periods of fresh-water discharge from the rivers and bayous. Renfro (1959a, 1959c); Pullen (1960, 1962).

P. nigromaculatus (LeSueur)—Black crappie*

Rare, predominantly a fresh-water species. Chambers and Sparks (1959).

Family Percidae—Perches

Etheostoma lepidum (Baird and Girard)—Greenthroat darter

Fowler (1945) reported this species as *Poecilichthys lepidus* (Baird and Girard), however, Hubbs (1954) notes that Fowler's record is based on *Etheostoma spectabile* Agassiz which would not be expected from the brackish water on Galveston Island.

Family Pomatomidae—Bluefishes

Pomatomus saltatrix (Linnaeus)—Bluefish *

Found in large schools during the summer in high salinity waters. Renfro (1959a); Arnold, Wheeler and Baxter (1960); Pullen (1962).

Family Rachycentridae—Cobias

Rachycentron canadum (Linnaeus)—Cobia*

Rare, young are found occasionally during the summer in high salinity waters.

Family Carangidae—Jacks and Pompanos

Caranx crysos (Mitchill)—Blue runner

Rare, reported from Lower Galveston Bay in 1963 by the Texas Parks and Wildlife Department (personal communication).

C. hippos (Linnaeus)—Crevalle jack*

Common during the warmer months throughout the bay system. Reid (1955b, 1956, 1957); Hoese (1959b); Renfro (1959a); Arnold, Wheeler and Baxter (1960); Pullen (1960, 1962).

C. latus Agassiz—Horse-eye jack

Rare, specimens of this jack were found in Upper Galveston Bay in extremely low salinity water. Pullen (1962).

Cholroscombrus chrysurus (Linnaeus)—Bumper*

Common, found during the warmer months in moderate to high salinity waters. Reid (1955a, 1955b, 1956, 1957); Hoese (1959b); Renfro (1959a); Arnold, Wheeler and Baxter (1960); Shidler (1960); Pullen (1960, 1962).

Hemicaranx amblyrhynchus (Cuvier)—Bluntnose jack*

Uncommon, found during the warmer months in moderate to high salinity waters. Reid (1955b, 1956, 1957) as *H. amblyrhynchus* (Cuvier and Valenciennes).

Oligoplites saurus (Bloch and Schneider) Leatherjacket*

Common during the warmer months in high salinity waters of shallow grassy flats. Reid (1955b, 1956); Hoese (1959b); Renfro (1959a); Arnold, Wheeler, and Baxter (1960); Shidler (1960); Pullen (1960, 1962).

Selene vomer (Linnaeus)—Lookdown*

Uncommon, occasionally frequenting high salinity waters. Hoese (1959b); Renfro (1959a); Arnold, Wheeler and Baxter (1960); Shidler (1960).

Seriola falcata Valenciennes—Almaco jack*

Uncommon, found during the summer near the jetties. This species has not previously been reported from Texas.

Trachinotus carolinus (Linnaeus)—Pompano*

Uncommon, found occasionally during the warmer months in high salinity waters. Reid (1956, 1957); Renfro (1959a); Arnold, Wheeler and Baxter (1960).

Vomer setapinnis (Mitchill)—Atlantic moonfish*

Uncommon, found occasionally during the warmer months in moderate to high salinity waters. Hoese (1959b); Renfro (1959a); Shidler (1960); Pullen (1960, 1962).

Family Coryphaenidae—Dolphins

Coryphaena hippurus Linnaeus—Dolphin

Rare, predominantly a marine species. Arnold, Wheeler and Baxter (1960).

Family Gerridae—Mojarras

Eucinostomus gula (Quoy and Gaimard)—Silver jenny*

Uncommon, found during the warmer months in high salinity waters of shallow vegetated areas. *Eucinostomus* sp. reported by Reid (1955b, 1956) is probably this species; *Eucinostomus* sp. reported by Hoese (1959b) is probably this species; Renfro (1959a); Arnold, Wheeler and Baxter (1960).

Family Pomadyasyidae—Grunts

Orthopristis chrysopterus (Linnaeus) Pigfish*

Common, found during the warmer months in high salinity waters. Fowler (1945); Reid (1955b, 1956); Hoese (1959a, 1959b); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1962); Stevens (1963b).

Family Sciaenidae—Drums

Aplodinotus grunniens Rafinesque—Fresh-water drum

Rare, predominantly a fresh-water species. Chambers and Sparks (1959).

Bairdiella chrysura (Lacépède)—Silver perch*

Common from spring through fall throughout the bay system. Reid (1955a, 1955b, 1956, 1957); Hoese (1959b); Renfro (1959a, 1959b); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1962).

Cynoscion arenarius Ginsburg—Sand seatrout*

Abundant all year throughout the bay system, but present in greatest numbers during the warmer months. Reid (1955a, 1955b, 1956, 1957); Chambers and Sparks (1959); Hoese (1959b); Renfro (1959b); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1961, 1962).

C. nebulosus (Cuvier)—Spotted seatrout*

Abundant all year throughout the bay system, but present in greatest numbers during the warmer months. Reid (1955a, 1955b, 1956, 1957); Chambers and Sparks (1959); Hoese (1959b); Renfro (1959a, 1959b, 1963); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1962); Stevens (1963a, 1963b).

C. nothus (Holbrook)—Silver seatrout*

Rare, appearing occasionally in high salinity waters. Fowler (1945); Hoese (1959b).

Larimus fasciatus Holbrook—Banded drum*

Uncommon, found in small numbers during all seasons in high salinity waters. Reid (1956, 1957); Chambers and Sparks (1959); Arnold, Wheeler and Baxter (1960); Chin (1961); Pullen (1962).

Leiostomus xanthurus Lacépède—Spot*

Abundant during the warmer months throughout the bay system. Fowler (1945); Reid (1955a, 1955b, 1956, 1957); Chambers and Sparks (1959); Hoese (1959b, 1959c); Renfro (1959a, 1959b); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1961, 1962).

Menticirrhus americanus (Linnaeus)—Southern kingfish*

Common throughout the year in moderate to high salinity waters. Fowler (1945); Reid (1956, 1957); Renfro (1959a); Shidler (1960); Pullen (1960, 1961, 1962).

M. littoralis (Holbrook)—Gulf kingfish

Rare, predominantly a marine species. Reid (1956, 1957).

Micropogon undulatus (Linnaeus)—Atlantic croaker*

Abundant all year throughout the bay system. Fowler (1945); Reid (1955a, 1955b, 1956, 1957); Chambers and Sparks (1959); Hoese (1959b, 1959c); Renfro (1959a, 1959b, 1963); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1961, 1962); Stevens (1963a, 1963b).

Pogonias cromis (Linnaeus)—Black drum*

Abundant throughout the year in moderate to high salinity waters. Reid (1955a, 1955b, 1956, 1957); Chambers and Sparks (1959); Hoese (1959a,

1959b); Renfro (1959a); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1962); Stevens (1963a, 1963b).

Sciaenops ocellata (Linnaeus)—Red drum*

Abundant throughout the year in moderate to high salinity waters. Reid (1955a, 1955b, 1956, 1957); Chambers and Sparks (1959); Hoese (1959b, 1959c); Renfro (1959a); Arnold, Wheeler and Baxter (1960); Chin (1961); Pullen (1960, 1962); Stevens (1963a, 1963b).

Stellifer lanceolatus (Holbrook)—Star drum*

Abundant throughout the year in moderate to high salinity waters, but found predominantly in the deeper waters of the channels. Fowler (1945); Reid (1955b, 1956, 1957); Chambers and Sparks (1959); Hoese (1959b); Renfro (1959a); Shidler (1960); Chin (1961); Pullen (1960, 1961, 1962).

Family Sparidae—Porgies

Archosargus probatocephalus (Walbaum)—Sheepshead*

Common all year in moderate to high salinity waters. Reid (1955b, 1956, 1957) as *A. oviceps* Ginsburg; Hoese (1959a, 1959b); Renfro (1959a); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1962); Stevens (1963a, 1963b).

Lagodon rhomboides (Linnaeus)—Pinfish*

Common all year in moderate to high salinity waters. Reid (1955a, 1955b, 1956, 1957); Chambers and Sparks (1959); Hoese (1959a, 1959b); Renfro (1959a); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1962); Stevens (1963b).

Family Ephippidae—Spadefishes

Chaetodipterus faber (Broussonet)—Atlantic spadefish*

Common during the warmer months in high salinity waters. Fowler (1945); Reid (1955b, 1956, 1957); Chambers and Sparks (1959); Renfro (1959a); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1961).

Family Trichiuridae—Cutlassfishes

Trichiurus lepturus Linnaeus—Atlantic cutlassfish*

Common during the warmer months in moderate to high salinity waters. Reid (1955b, 1956, 1957); Chambers and Sparks (1959); Hoese (1959b); Renfro (1959a); Arnold, Wheeler and Baxter (1960); Shidler (1960); Pullen (1960, 1961).

Family Scombridae—Mackerels

Scomberomorus maculatus (Mitchell)—Spanish mackerel*

Uncommon, found occasionally during the summer in moderate to high salinity waters. Reid (1956, 1957); Renfro (1959a); Pullen (1960); Shidler (1960).

Family Eleotridae—Sleepers

Dormitator maculatus (Bloch)—Fat sleeper

Uncommon, a fresh-water species whose range is extended throughout the bay system during periods of fresh-water flooding. Evermann and Kendall (1894); Chambers and Sparks (1959); Arnold, Wheeler and Baxter (1960); Pullen (1962).

Family Gobiidae—Gobies

Evorthodus lyricus (Girard)—Lyre goby

Rare. Jordan and Gilbert (1883) as *Gobius lyricus* (Girard); Fowler (1945) as *Gobionellus lyricus* (Girard); Arnold, Wheeler and Baxter (1960).

Gobioides broussonneti Lacépède—Violet goby*

Uncommon, residing primarily in shallow, low salinity waters of lakes and flats. Chambers and Sparks (1959); Renfro (1959a); Chin (1961); Pullen (1962).

Gobionellus boleosoma (Jordan and Gilbert)—Darter goby*

Uncommon, found occasionally in waters of low salinity. Reid (1956, 1957); Hoese (1959a); Renfro (1959a); Pullen (1960, 1962).

G. hastatus Girard—Sharptail goby *

Uncommon, found scattered throughout the bay system, but most abundant in waters of high salinity. Fowler (1945) as *G. h. hastatus* Girard; Renfro (1959a); Arnold, Wheeler and Baxter (1960); Pullen (1960); Shidler (1960) as *G. oceanicus*; Pullen (1961) as *Gobius hastatus*; Pullen (1962).

G. shufeldti (Jordan and Evermann)—Freshwater goby

Rare, apparently restricted to waters of low salinity. Chambers and Sparks (1959); Chin (1961).

Gobiosoma bosci (Lacépède)—Naked goby*

Common, found all year throughout the bay system, but most abundant in the shallow lakes and flats. Hoese (1959a); Renfro (1959a, 1959b); Arnold, Wheeler and Baxter (1960) as *G. molestum* Girrard; Shidler (1960); Chin (1961); Pullen (1960, 1962).

G. robustum Ginsburg—Code goby

Rare, collected by Hinton D. Hoese in grass flats in lower West Bay (personal communication).

Microgobius gulosus (Girard)—Clown goby*

Common, residing year round throughout the bay system, but most abundant in the waters of shallow lakes and flats. Pullen (1960, 1962).

M. thalassinus (Jordan and Gilbert)—Green goby*

Uncommon, found occasionally in the waters of the shallows and flats. Fowler (1945).

Family Scorpaenidae—Scorpionfishes

Scorpaena calcarata Goode and Bean—Smoothhead scorpionfish*

Rare, apparently restricted to deep waters of high salinity.

Family Triglidae—Searobins

Prionotus scitulus Jordan and Gilbert—Leopard searobin*

Uncommon, apparently restricted to high salinity waters.

P. tribulus Cuvier—Bighead searobin*

Common, found during all seasons throughout the bay system. Fowler (1945); Reid (1956) as *P. t. crassiceps* Ginsburg; Renfro (1959a); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1962).

Family Uranoscopidae—Stargazers

Astrocopus y-graecum (Suvier)—Southern stargazer*

Rare, this species is occasionally found in the deeper high salinity waters of the bay system. Fowler (1945); Renfro (1959a); Chin (1961).

Family Clinidae—Clinids

Labrisomus nuchipinnis (Quoy and Gaimard)—Hairy blenny.

Rare, apparently restricted to waters of high salinity. Hoese (1959a); Arnold, Wheeler and Baxter (1960).

Family Blenniidae—Combtooth blennies

Chasmodes bosquianus (Lacépède)—Striped blenny*

Common in waters of high salinity. Hoese (1959a); Shidler (1960); Pullen (1962).

Hypsoblennius ionthas (Jordan and Gilbert)—Freckled blenny*

Common in high salinity waters near oyster reefs and around the jetties. Jordan and Gilbert (1883) as *Isesthes scrutater* sp. nov.; Hoese (1959a); Hofstetter (1959); Pullen (1960, 1962).

Family Ophidiidae—Cusk-eels

Ophidion welshi (Nichols and Breder)—Crested cusk-eel*

Uncommon, found occasionally in high salinity waters.

Rissola marginata (De Kay)—Striped cusk-eel*

Uncommon, found in moderate to high salinity waters. Pullen (1960, 1962).

Family Stromateidae—Butterfishes

Peprilus paru (Linnaeus)—Northern harvestfish*

Common during the warmer months in waters of moderate to high salinity. Fowler (1945); Reid (1955b, 1956, 1957); Renfro (1959a); Pullen (1960, 1962).

Poronotus burti (Fowler)—Butterfish* (*see* Collete, 1963)

Common during the warmer months in waters of high salinity. Fowler (1945) as *Peprilus burti* Fowler; Renfro (1959a) as *Poronotus triacanthus* (Peck); Pullen (1960, 1962) as *Poronotus triacanthus* (Peck).

Family Mugilidae—Mullets

Mugil cephalus Linnaeus—Striped mullet*

Abundant all year throughout the bay system. Fowler (1945); Reid (1955a, 1955b, 1956, 1957); Chambers and Sparks (1959); Hoese (1959b); Renfro (1959a, 1959b); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1961, 1962); Stevens (1963b).

M. curema Valenciennes—White mullet

Uncommon, apparently restricted to high salinity waters. Reid (1955a, 1955b, 1956, 1957) as *M. curema* (Cuvier and Valenciennes); Chambers and Sparks (1959); Hoese (1959b); Renfro (1959a); Pullen (1962); Stevens (1963b).

Family Atherinidae—Silversides

Membras martinica (Valenciennes)—Rough silverside*

Common along shore lines, usually in high salinity waters. Reid (1955a, 1955b, 1956, 1957) as *M. m. ragrans* (Goode and Bean); Renfro (1959a); Arnold, Wheeler and Baxter (1960) as *M. ragrans ragrans* (Goode and Bean); Pullen (1960, 1962); Stevens (1963b).

Menidia beryllina (Cope)—Tidewater silversides*

Common all year throughout the bay system. Fowler (1945); Reid (1955b, 1956, 1957) as *M. b. peninsulae* (Goode and Bean); Chambers and Sparks (1959); Renfro (1959a); Arnold, Wheeler and Baxter (1960) as *M. b. pensacolae* (Goode and Bean); Shidler (1960); Chin (1961); Pullen (1960, 1961, 1962); Stevens (1963b).

Family Polynemidae—Threadfins

Polydactylus octonemus (Girard)—Atlantic threadfin*

Common during the warmer months in high salinity waters. Fowler (1945); Reid (1955a, 1955b, 1956, 1957); Chambers and Sparks (1959); Hoese (1959b); Renfro (1959a); Arnold, Wheeler and Baxter (1960); Chin (1961); Pullen (1960, 1962).

ORDER PLEURONECTIFORMES (HETEROSOMATA)

Family Bothidae—Lefteye flounders

Ancylopsetta quadrocellata Gill—Ocellated flounder *

Uncommon, found occasionally in the Houston Ship Channel. Fowler (1945); Hoese (1959b); Pullen (1960, 1962).

Citharichthys spilopterus Günther—Bay whiff*

Common during all seasons throughout the bay system, but most abundant in waters of moderate to high salinity. Fowler (1945); Reid (1955a, 1955b, 1956, 1957); Hoese (1959b, 1959c); Renfro (1959a); Shidler (1960); Chin (1961); Pullen (1960, 1961, 1962).

Etropus crossotus Jordan and Gilbert—Fringer flounder*

Common during all seasons in moderate to high salinity waters. Fowler (1945) as *E. crossotus* Gilbert; Hoese (1959b).

Paralichthys albigutta Jordan and Gilbert—Gulf flounder *

Uncommon in this bay system.

P. lethostigma Jordan and Gilbert—Southern flounder*

Abundant all year throughout the bay system, but present in greatest numbers in moderate to high salinity waters. Chandler (1935); Fowler (1945); Reid (1955a, 1955b, 1956, 1957); Hoese (1959a); Renfro (1959a, 1959b); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1962); Stevens (1963a, 1963b).

P. squamilentus Jordan and Gilbert—Broad flounder

Rare. Baughman (1950a).

Family Soleidae—Soles

Archirus lineatus (Linnaeus)—Lined sole*

Common throughout the year in moderate to high salinity waters. Fowler (1945) as *A. achirus* (Linnaeus); Reid (1955b, 1956, 1957); Renfro (1959a); Chin (1961); Pullen (1960, 1962).

Trinectes maculatus (Bloch and Schneider)—Hogchoker*

Common throughout the year in moderate to high salinity waters. Fowler (1945) as *Archirus fasciatus* Lacépède; Chambers and Sparks (1959) as *T. maculator* (Bloch); Hoese (1959b); Renfro (1959a, 1959b); Shidler (1960); Chin (1961); Pullen (1960, 1962).

Family Cynoglossidae—Tonguefishes

Symphurus plagiusa (Linnaeus)—Blackcheek tonguefish*

Common throughout the year in moderate to high salinity waters. This species is very abundant in the deep waters of the Houston Ship Channel. Fowler (1945); Reid (1955b, 1956); Hoese (1959b); Renfro (1959a); Chin (1961); Pullen (1960, 1961, 1962).

ORDER ENCHENEIFORMES (DISCOCEPHALI)

Family Encheneidae—Remoras

Echeneis naucrates Linnaeus—Sharksucker

Uncommon, found occasionally attached to rays and sharks. Pullen (1960, 1962).

ORDER GOBIESOCIFORMES (XENOPTERYGII)

Family Gobiesocidae—Clingfishes

Gobiesox strumosus Cope—Skilletfish*

Common in waters of high salinity. Hoese (1959a); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1962).

ORDER TETRAODONTIFORMES (PLECTOGNATHI)

Family Monacanthidae—Filefishes

Stephanolepis hispidus (Linnaeus)—Planehead filefish* (*see* Berry and Vogele, 1961)

Common in high salinity waters. Reid (1955b, 1956) as *Monacanthus hispidus* (Linnaeus); Shidler (1960) as *Monacanthus hispidus*.

Family Tetraodontidae—Puffers

Lagocephalus laevigatus (Linnaeus)—Smooth puffer*

Rare, collected in 1963 from East Bay by personnel of the Texas Parks and Wildlife Department and from West Bay by a local fisherman (personal communications).

Sphaeroides nephelus (Goode and Bean)—Southern puffer*

Common during summer and fall in high salinity waters. Reid (1955a, 1955b, 1956, 1957); Hoese (1959b); Renfro (1959a); Shidler (1960); Chin (1961); Pullen (1960, 1961, 1962).

S. testudineus (Linnaeus)—Checkered puffer

Rare. Baughman (1950b)

Family Diodontidae—Porcupinefishes

Chilomycterus schoepfi (Walbaum)—Striped burrfish*

Common during the warmer months in high salinity waters. Reid (1956, 1957); Renfro (1959a); Shidler (1960).

Diodon hystrix Linnaeus—Porcupinefish.

Rare. Baughman (1950b).

ORDER BATRACHOIDIFORMES (HAPLODOCI).

Family Batrachoididae—Toadfishes

Opsanus beta (Goode and Bean)—Gulf toadfish*

Uncommon, found in high salinity waters. Hoese (1959a, 1959b); Renfro 1959a, 1959b); Arnold, Wheeler and Baxter (1960); Chin (1961); Pullen (1960, 1962).

Porichthys porosissimus (Cuvier)—Atlantic midshipman*

Common during all seasons in moderate to high salinity waters, but most abundant in the ship channel and around oyster reefs. Fowler (1945) as *Nautopaedium porosissimum* (Valenciennes); Hoese (1959b); Renfro (1959a); Shidler (1960); Pullen (1960, 1962).

ORDER LOPHIIFORMES (PEDICULATI)

Family Antennariidae—Frogfishes

Histrio histrio (Linnaeus)—Sargassumfish

Although not a permanent inhabitant, this fish may be found upon occasion swimming near sargassum weed which has drifted in from the Gulf. Renfro (1959a).

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REPRINT FROM
Calif. Fish and Game, 51 (4) :298–299. 1965

THE PACIFIC BONITO, *SARDA CHILIENSIS* (CUVIER), IN PUGET SOUND, WASHINGTON

The Pacific bonito is uncommon north of Point Conception, California (Radovich, 1961), although it is known to occur in Alaskan waters at about lat. 60° N. (Quast, 1964). This fish has been taken infrequently off the west coast of Vancouver Island, and two have been recorded from inland marine waters of British Columbia (Clemens and Wilby, 1961); it has seldom been reported from Puget Sound.

Kincaid (1919) noted that the Pacific bonito occurred rarely in Puget Sound but he did not mention numbers, locations, or season of occurrence. In 1962, two specimens were caught in salmon gill nets, the first in October about 4 miles north of Seattle, and the second in November about 3 miles west of Seattle (Fishermen's News, 1963*a*). The latter fish was placed in the University of Washington Ichthyological Museum (UW 16529). In September 1963, two bonito were taken from a gill net which had been set for salmon off Carkeek Park, Seattle (Fishermen's News, 1963*b*).

The most recent capture of a Pacific bonito, and the one which prompted preparation of this note, was made by John W. Michaels while fishing commercially for salmon. It was taken off Point Monroe, the northern tip of Bainbridge Island, 5 miles west of Seattle, on November 22, 1964, between 10 PM and midnight, in the upper half of a 5½-inch, stretch-mesh gill net fished at a maximum depth of 25 feet. The specimen, a female, weighed 4.3 kg and was 67.3 cm fork length. The paired ovaries weighed 74 gm, and the stomach was devoid of food or parasites. Fifty of the larger ova had a mean diameter of 0.38 mm, ranging from 0.30 to 0.50 mm. The fish was deposited in the University of Washington Ichthyological Museum (UW 18499). Other fishes caught in the gill net with it included 200–300 spiny dogfish (*Squalus acanthias*), 40–50 Pacific hake (*Merluccius productus*), and 20 chum salmon (*Oncorhynchus keta*).

The water temperature was not measured at the location of the catch, but was probably 47°–50° F, estimated from measurements made in nearby portions of Puget Sound. This is about 10° F colder than November temperatures immediately south of Point Conception, California, and up to 32° F colder than off Baja California (Johnson, 1961), in an area where the bonito is common. The salinity of central Puget Sound during the autumn, according to data from earlier years, is between 29 and 30.5‰ (McLellan, 1954), as compared with oceanic salinities off southern California of 33–34‰ (Reid *et al.*, 1958). Bonnot (1931) reported a bonito from waters which were probably of even lower salinity, but he did not give a salinity value.

The occurrence of bonito in Puget Sound reflects the general preference of fish of the genus *Sarda* for coastal waters (Fitch and Craig, 1964). Fitch (pers. commun.) states that at times bonito are abundant

in harbors and bays of southern California, and that they are taken by sportsmen fishing from docks or along shore.

It is interesting that five Pacific bonito were captured within 6 miles of Seattle at about the same time of the year. All were taken in salmon gear, as was the one reported at Sooke, British Columbia (Clemens and Wilby, 1961).

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—*Benjamin G. Patten, Duane T. Rodman, and Kenneth D. Waldron, U.S. Bureau of Commercial Fisheries, Seattle, Washington, March 1965.*

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Reprinted from COPEIA, 1965, No. 1, March 18
pp. 114–115

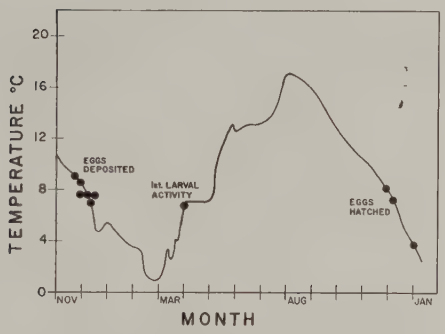

Fig. 1. Water temperautres during deposition, incubation, and hatching of egg cases of *Raja erinacea*.

INCUBATION OF FALL-SPAWNED EGGS OF THE LITTLE SKATE, *RAJA ERINACEA* (MITCHILL).—The little skate, *Raja erinacea* (Mitchill), has a summer and fall season for spawning in New England waters, and eggs laid during the summer period under aquarium conditions of slightly higher temperatures than those in nature require 5 to 6 months to hatch, which is perhaps an underestimate of the natural incubation period (Merriman, Olsen, Wheatland, and Calhoun 1953, Mem. Sears Found. Mar. Res. 1, Part II:187–194). Little is known regarding the incubation time of eggs deposited in November–January, except for the postulation of the authors previously cited, that these eggs would take longer to hatch than those deposited during the June–July period. This note provides information about the incubation time of fall-spawned eggs.

At the U. S. Bureau of Commerical Fisheries Biological Laboratory, Boothbay Harbor, Maine, 6 *R. erinacea* eggs were deposited in late November and early December by specimens held in aquaria. The water temperature of the aquaria during this period fluctuated between 7 and 8 C, and closely approximated that of inshore water. The egg cases were candled daily. The first larval activity was recorded 21 March 1962, and initial activity in the others on 2 April, 14 May, and 4 June 1962. No development was evident in 2 of the 6 capsules. The larva which showed activity for the first time on 2 April ceased being active on 25 May.

The egg cases were watertight until the larvae began to develop their external gill system (seen by candling). At that time, water began to pass from the horn slits of the egg case. The first hatching took place 26 November 1962 (368 days after deposition). The remaining 2 larvae hatched on 8 December (363 days after deposition) and 27 December 1962 (372 days after deposition).

The temperature of the water from time of egg deposition to time of larval emergence from the egg cases is shown in Fig. 1. Of particular interest is that the temperature at the time of egg deposition, first larval activity, and hatching of the young is within 4 degrees of each other and that there was a longer incubation period in comparison with summer-deposited eggs as surmised

TABLE 1. TIME OF INCUBATION, SEX, MEASUREMENTS (IN MM), AND WEIGHTS (G) OF NEWLY HATCHED *R. erinacea*.

Incubation Time	Total Length	Tail Length	Width	Weight	Sex
368 days	104	62	58	6.1	F
363 days	105	60	59	6.0	F
372 days	112	60	61	6.3	M

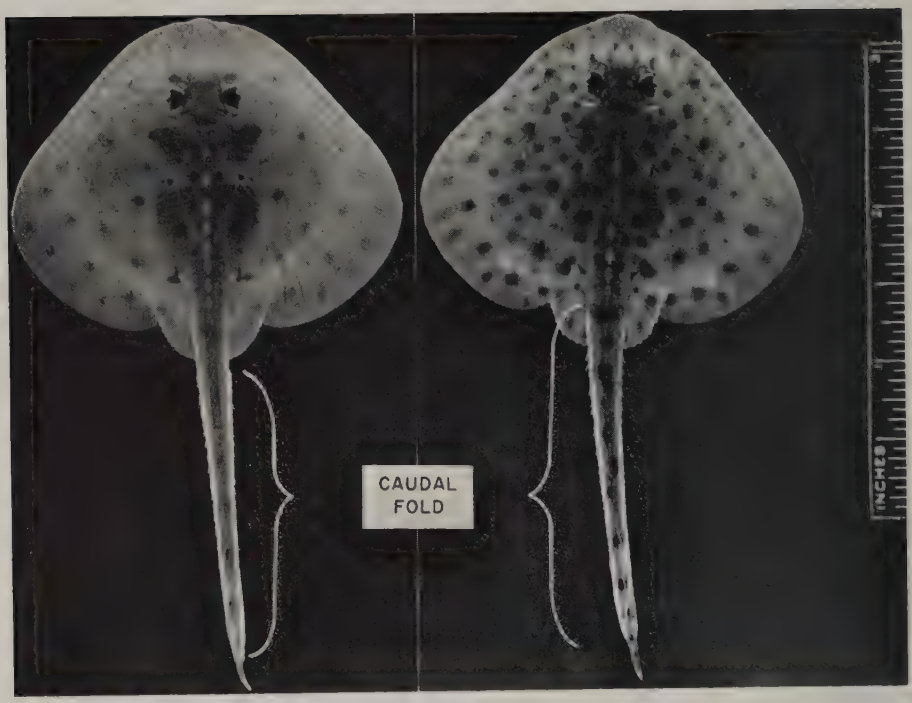

Fig. 2. Dorsal view of newly hatched female and male skate, *Raja erinacea*.

(Richards, Merriman, and Calhoun 1963, Bull. Bing. Oceanogr. Coll., 18:5–67), and this incubation period required 12 months more or less before actual hatching.

The total length, maximum width (pectorals), weight, and sex of the 3 newborn larvae are shown in Table 1. The range in total length from 104 mm to 112 mm is slightly greater than the 96 mm to 101 mm reported by Bigelow and Schroeder (1953, U. S. Fish Wildl. Serv., Fish. Bull. 74, 53: 69) for spring-hatched skates. The hatching weights are also greater than previously reported, Merriman *et al.* (*op. cit.*).

Dorsal views of the newborn female and male skates are shown in Fig. 2. In the male, the caudal fold begins near the origin of the tail and is spiny. In the female, the caudal fold originates several millimeters from the dorsal fin and the spines in the area from point of tail origin to the caudal fold were much less prominent than those in the male, a characteristic used to differentiate the immature male from immature female in these tank observations.—Frank E. Perkins, *U. S. Bureau of Commercial Fisheries Biological Laboratory, Boothbay Harbor, Maine.*

Made in United States of America
Reprinted from The Journal of Wildlife Management
Vol. 29, No. 4, October 1965
pp. 688–693

DRUGS FOR HANDLING FUR SEALS

by Richard S. Peterson

DRUGS FOR HANDLING FUR SEALS

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Abstract: Four drugs that alter central nervous system function and three that affect peripheral nerve sites were tested on northern fur seals (*Callorhinus ursinus*) in attempts to obtain field immobilization. Nearly 300 animals were injected during the summers of 1961, 1962, and 1963 at St. Paul Island, Alaska. Most of the subjects were adult males on breeding grounds. Automatic projectile syringes were used. Phencyclidene at dosages of 0.10–0.20 mg/kg was useful as a long-lasting depressant, and succinylcholine at dosages of 0.30–0.37 mg/kg was useful as a short-acting paralytic agent. Thiopental sodium, propiopromazine, insulin, nicotine, and gallamine were also tested.

Research on the biology of northern fur seals has been under way since 1940. Most of the studies have been based upon specimens killed for scientific or commercial purposes or upon young animals caught by hand. The trend toward more extensive physiological and behavioral studies has required the development of techniques for

handling and marking the older animals. This paper describes experiments with various drugs as an approach to the problem. The primary objective was to find a technique for brief field immobilization of the adult, territorial males.

Facilities and support for the study were provided by the U. S. Fish and Wildlife Service and The Johns Hopkins University. The guidance of F. Wilke and W. J. L. Sladen is gratefully acknowledged. For assistance with the field work, I am particularly indebted to D. B. Kooyman, D. C. Boggs, I. Emanuel, L. Stepetin, D. Bourdukofsky, and V. E. Lekanof. Palmer Chemical and Equipment Co.; Abbott Laboratories; Burroughs Wellcome, USA; Eli Lilly and Co.; Parke, Davis and Co.; and The Squibb Institute provided equipment and drugs.

METHODS

Wildlife workers have tested many drugs seeking the paralysis or calming needed to handle animals in the field (Talbot and Talbot 1962, Flook et al. 1962). Automatic projectile syringes have greatly facilitated this work. Experiments have recently been done on pinnipeds (Ling and Nicholls 1963, Lewell and Smith 1965, Flyger et al. 1965), but in 1961 I was unaware of any previous successful field tests with seals, except for the pioneering efforts of the late Carl R. Eklund in Antarctica in 1957 (Unpublished records).

Because information applicable to pinnipeds was lacking, initial dosages were based upon those used for carnivores, particularly bears (Craighead et al. 1960, Black 1958). Except as otherwise noted, drugs were administered from automatic projectile syringes equipped with 2-inch barbed needles. The injection target was usually the latissimus dorsi muscle, posterior to the axilla. The syringes were fired from gas-operated rifles at ranges of 5–30 feet.

Several characteristics of fur seals complicated drug experiments. A thick blanket of subcutaneous blubber, which may account for as much as one-third a bull's weight, made intramuscular deposition difficult. Quantities of fat-soluble drugs might lodge in these stores of adipose tissue, causing markedly altered effects (Brodie and Hogben 1957:368–372, Frey 1959).

Most work on the bulls was done during their spring fast and coincidental breeding season, a period of up to 70 days (Bartholomew and Hoel 1953:425). During this time bulls are very aggressive toward humans (Kenyon 1960). Because of the unusual behavior and physiology of this period, drugs may affect the animals differently at other times of the year.

Another complication was unusual fighting among the bulls. Breeding territories are maintained by elaborate ceremonies, generally without much fighting (Peterson 1965). But when a drugged bull behaved abnormally, he was sometimes attacked violently. Considerable human effort was needed to protect drug-weakened animals, and this limited the usefulness of drugs having prolonged effects.

Judging the weight of seals from their appearance was difficult; only six bulls were actually weighed. From their weights, combined with others from files of the Marine Mammal Biological Laboratory, I established three broad weight categories for bulls: *small*, 150–250 kg; *average*, 250–300 kg; and *large*, over 300 kg. Small trial dosages were used to test individual reactions to most drugs, especially for those with a low therapeutic ratio (the ratio between the lethal and effective dosages).

When apnea occurred during experiments with paralytic drugs, several meth-

ods were used in attempts to restore breathing. Lifting the animal's head sometimes provoked gasping. Artificial respiration by intermittent pressure on the thorax was sometimes successful. Use of an oxygen tank to inflate the lungs of paralyzed seals failed, apparently because of leakage around a catheter through the relaxed glottis. Electroshock, from a cattle prod, did not prove useful as it has for other animals (L. Irving, personal communication).

RESULTS

Central Nervous System Depressants

Thiopental Sodium.—Barbiturates of this type can be administered intravenously, intramuscularly, or rectally; however, the usual intravenous route was not practical for seals. Five territorial bulls were given intramuscular injections of "Cap-Chur-Barb" (Palmer Chemical and Equipment Co.) in dosages of from 40 to 200 mg/kg. Only 200 mg/kg, which is near the lethal minimum for other species, caused observable reaction. Slight ataxia was observed after 30 minutes in one animal that received this dosage, suggesting that even massive intramuscular dosages of barbiturates may be absorbed too slowly for field work on fur seals.

Four young seals (aged 2–4 years) were given "Pentothal" (Abbott Laboratories) rectally from suppositories in dosages of 26–80 mg/kg. There was no apparent sedation during 2 hours following administration.

Phencyclidene.—This drug reportedly inactivates voluntary motor function by inhibition of the central nervous sites that control sensory perception (Chen and Weston 1960:137). "Sernylan" (Parke, Davis and Co.) was given intramuscularly to nine territorial bulls in dosages between 0.09 and 0.30 mg/kg. The effective range for immobilization was 0.10 mg/kg–0.20 mg/kg. Among five animals successfully immobilized, the latent period averaged 5.0 minutes; complete recovery required 1–7 hours. Two animals succumbed to dosages of 0.26 and 0.30 mg/kg, which first induced a "cataleptoid state," described by Chen et al. (1959:242), that continued for up to 24 hours, after which the animals had to be killed.

The dosage rate for fur seal bulls is remarkably low and possibly is related to fasting. In young captive fur seals a dosage of 0.5 mg/kg is reported effective (Kroll 1962:136). Recently, the phencyclidene dosage for elephant seals that were probably fasting was also found to be surprisingly low (M. E. Q. Pilson, personal communication).

Propiopromazine.—This tranquilizer, "Tranvet" (Abbott Laboratories), was effective on fur seals of all ages and both sexes, including pups (aged 1–4 months). Hand syringe injections were given to 30 young seals (under 5 years). A dosage of 1.0 mg/kg produced some calming; 2.0 mg/kg produced tranquilization sufficient for laboratory procedures such as closeup photography; and 3.0–4.0 mg/kg induced sedation and ataxia. The latent period was about 15 minutes, and the effects continued as long as 24 hours, although aggressive activity gradually returned after 1–2 hours.

During the breeding season, fur seal bulls are too dangerous to be handled with tranquilizers, but in late summer they are less aggressive. After the breeding season, 11 bulls were given dosages near 2.0 mg/kg with projectile syringes. Calming was sufficient to allow easy capture of the animals with ropes and then quick tagging.

Insulin.—In the search for an immobilizing agent with a high therapeutic ratio, quick reversibility, and subcutaneous administration, large doses of insulin were

tried on the seals. Injections were given four young animals, aged 2–5 years, two from hand syringes and two from projectiles. Onset of coma was very delayed, requiring 3.5 hours after injection of 80 USP units in one animal. Two other animals were given 120 USP units each. This larger dosage reduced the latent period, but resulted in uncontrollable coma a few hours later (see below). The fourth animal was given two injections of 75 USP units each, separated by 1 hour, following the multiple-dose technique of Laqueur and LaBurt (1960). Probably the total quantity was too great, as coma also recurred in this case.

Intramuscular injection of 2 mg "Glucagon" (Eli Lilly and Co.) restored consciousness within 10 minutes in three animals tested. Two of them later succumbed to a secondary coma which, unlike the first coma, could not be terminated with glucagon (possibly the result of exhaustion of glycogen stores). One animal, originally given 80 units of insulin, responded to glucagon and showed no aftereffects. The fourth animal, given intravenous dextrose rather than glucagon, failed to regain consciousness and had to be destroyed.

The technique seems worth further testing, particularly if the latent period could be reduced.

Peripheral Nerve Inhibitors

Nicotine.—Alkaloidal nicotine (Palmer Chemical and Equipment Co.) formerly was used extensively for field immobilization of wildlife (Jenkins et al. 1956). Preliminary tests on fur seal bulls by Abegglen et al. (1960:69) indicated a low therapeutic ratio, and their findings were substantiated by my 14 further tests.

Dosages of 4.0–5.0 mg/kg were tolerated, causing ataxia and tremor 15–20 minutes after injection into five animals, but complete immobilization did not occur. Smaller dosages caused no observable reaction in six bulls. Death occurred in three animals receiving overdosage (5.6, 6.2, and 7.0 mg/kg) after periods of 50 minutes to 3 days following injection. Axial muscle innervation evidently was damaged in one bull that received 4.8 mg/kg, and it finally had to be killed after several days of abnormal behavior.

In brief, the drug was not successful for immobilizing fur seals.

Succinylcholine.—This motor end plate depolarizing agent has been used widely on wildlife (Buechner et al. 1960) and was found useful for fur seals. Three evidently identical varieties were used: "Anectine" (Burroughs Wellcome, USA), "Quelicin" (Abbott Laboratories), and "Sucostrin" (The Squibb Institute).

Table 1, Part A, summarizes the results of experiments with 93 territorial bulls. Of these, 13 never became paralyzed sufficiently for handling; 58 were immobilized; and 18 succumbed to overdosage, mostly during early trials. The useful dosage range was 0.30–0.37 mg/kg, combining all weight classes.

Among bulls successfully immobilized, latent period averaged 12 minutes. The first effect was quivering of the foreflipper muscles, followed by ataxia. Animals fell to the ground 15–25 minutes after injection. Head-lifting was the last voluntary activity and the first one regained during recovery. Immobilization lasted 3–10 minutes, followed by 30–60 minutes of gradual recovery to normal activity. In no case was recovery so abrupt that workers were taken by surprise.

Table 1, Part B, summarizes experiments with 22 other territorial bulls, during which 150 TR-units of hyaluronidase were added to each injection. This enzyme ("Hyazyme," Abbott Laboratories) reportedly

Table 1. Intramuscular injections of succinylcholine in male fur seals, 1961–63, St. Paul Island, Alaska.

Animals' Estimated Weight Range	Effect of Injection	Number of Injections*	Mean Quantity (mg)	Mean Dosage (mg/kg)†	Latent Period (minutes)
PART A					
small	subparalytic	20	57	0.31	16
150–250 kg	paralytic	9	62	0.35	14
	lethal	4	70	0.40	8
average	subparalytic	100	70	0.29	18
250–300 kg	paralytic	45	89	0.37	12
	lethal	14	91	0.37	9
large	subparalytic	11	77	0.26	24
over 300 kg	paralytic	4	94	0.34	13
PART B					
Hyaluronidase	subparalytic	9	49	0.24	7
added‡	paralytic	20	69	0.31	5
	lethal	1	70	0.35	3

* Several subparalytic trial injections usually were made per individual. The total number of individuals injected was 115.

† Mean dosage is based on calculations for each individual, not the summarized weight or dosage ranges.

‡ All weight ranges pooled in this series due to small sample size. 150 TR-units hyaluronidase were added to each injection, mixed with succinylcholine.

speeds absorption by depolymerizing the hyaluronic acid of interstitial tissue (Wilson and Schild 1959:350). Mixing it with succinylcholine evidently reduced the latent periods and the required dosage. But the experiments were performed later in the season than those using succinylcholine alone, so changes might have occurred in workers' skill or in reactivity of the animals.

A captive 2-year male was given succinylcholine at dosage 2.0 mg/kg in a middorsal artery (probably the vertebral) with a hand syringe. Radical differences from the reaction to intramuscular injections were immediately evident. Immobilization and arrest of breathing occurred 45 seconds after the injection and lasted for 2.5 minutes. Eight minutes after injection, recovery was complete.

In conclusion, succinylcholine was found generally useful for brief field immobilization of the seals. The primary disadvantage is the low therapeutic ratio, requiring trial dosages on each individual (since weights of the animals were not known exactly) and resulting delay. No other fast-acting drug, however, was found as successful.

Gallamine.—"Flaxedil" (Lederle Laboratories), a motor end plate polarizing agent, is easily counteracted by anticholinesterase. However, the side effects of injection of this antidotal enzyme in wildlife are reportedly undesirable (Talbot and Talbot 1962:82–83), and it was not tested on fur seals.

Gallamine alone was given to three territorial bulls from projectile syringes and to five adult females from hand syringes. Dosage was 2.2 mg/kg in all cases. The two bulls and two of the females succumbed within an hour, after terminal arrest of breathing. Another female died after 3 hours, while the remaining two showed little reaction to the injection.

The results suggest either high variability in reaction to this drug or a low therapeutic ratio. But antagonistic drugs usually are considered necessary to field work with gallamine so further experiments might prove this drug more useful.

CONCLUSIONS

Among the central nervous system depressants tested, phencyclidene was the most useful for field immobilization of fur seals. Insulin coma may prove useful after more experimentation. Propiopromazine was found to be a good tranquilizer but could not be used for safe handling of the aggressive bulls. The primary disadvantage of these central nervous system drugs was the long duration of their effects. This makes them difficult to use on noncaptive wild animals which, like fur seals, require protection from predators or competitors while unconscious.

Brief immobilization was characteristic of the peripherally effective paralytic drugs. Among those tested, succinylcholine proved the most useful, but considerable experience was necessary for effective use of it. Weight estimation was especially critical, for the effective and lethal dosages were dangerously close together.

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Received for publication January 29, 1965.

Reprinted from Biological Problems in Water Pollution, Third Seminar,
August 13-17, 1962, p. 202-210.

ACCUMULATION OF RADIONUCLIDES AND THE EFFECTS OF RADIATION ON MOLLUSCS

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U.S. Department of Health, Education and Welfare
Public Health Service Publication No. 999-WP-25
Division of Water Supply and Pollution Control
Cincinnati, Ohio
1965

ACCUMULATION OF RADIONUCLIDES AND THE EFFECTS OF RADIATION ON MOLLUSCS

Thomas J. Price *

Molluscan shellfish are among the most economically important organisms inhabiting estuarine waters. These animals feed by removing suspended particles from large volumes of water filtered through their gills. This filtered material includes phytoplankton, protozoa, bacteria, non-living detritus, and suspended inorganic particles. Most material is removed in particles entrapped in the mucous net of the gills; these mucoid particles are then transported along ciliary tracts to the labial palps where they are either ingested or rejected as pseudofeces. These mechanisms of filtering, transporting, and sorting are complex.

The principal food of molluscan shellfish is phytoplankton. These single-cell algae, because of their vast numbers and small size, present large surfaces for the direct adsorption of elements and their radionuclides (Goldberg, 1952; Rice, 1953; Rice and Willis, 1959). Since many molluscs are both filter feeders and bottom dwellers, phytoplankton with its associated elements and their isotopes is available as food both when alive in suspension and after death as settling estuarine detritus. It is known that phytoplankton will concentrate certain nuclides (Rice, 1953, 1956; Chipman, Rice, Price, 1958); thus shellfish may become exposed to an amount of radioactivity over that of the surrounding medium when feeding on radioactive plankton. Molluscan shellfish can obtain nutritive elements and their radioisotopes either from ingested food or from the surrounding water. Shellfish, by accumulating radioactivity, also may become an important link in the passing of radioactivity to higher trophic levels.

Estuaries in which a great many of the economically important molluscs are found have become potential areas of radioactive pollution. These bodies of water are collecting basins for drainage from the surrounding land masses. Pollutants reach estuaries either by leaching from the surrounding soil or in water from contaminated rivers. Within the past 15 years, the number of reactors and other possible sources of accidental release of radioisotopes into estuarine waters has increased. Many radioactive isotopes have become important because of their release in effluents from the various types of reactors. The increased number of licensed isotope users has created a problem of disposing of radioactive wastes. Already there are a number of nuclear ships adding to radioactive wastes released into marine waters. A large percentage of the increased radioactive fallout from nuclear detonations might possibly find its way into the oceans. Therefore, it is important that information be obtained so that the biological cycling of radioactive materials can be followed.

Radioactive isotopes have a common characteristic in that they emit ionizing rays and particles that are damaging to living plants and animals. Radiation occurs both from radioactive materials in the water and nuclides ingested by the aquatic organism. Selective accumulation of activity in certain tissues of organisms may result in localized damage. Harmful effects to the biota may be classified as somatic or genetic according to whether the effect damages the immediate physiological functions or tissues of the animal or involves the reproductive processes thus resulting in abnormalities in subsequent generations.

The accumulation of radioactive materials and the effects of radiation on marine organisms are of importance since they can affect man. There is a possibility that radioactive contaminants may reach man in high concentrations through seafood. Also, there is concern that the abundance of these marine organisms may be diminished from changes brought about by radiation injury.

The following is a report of experimental work carried out at the Radiobiological Laboratory of the Bureau of Commercial Fisheries, Beaufort, North Carolina, a cooperative project of the U. S. Fish and Wildlife Service and the Atomic Energy Commission.

The author wishes to express his appreciation to Dr. A. A. Armstrong, School of Textiles, North Carolina State College, Raleigh, North Carolina, for permission to use their cobalt-60 source.

The accumulation and retention of cesium-137, cerium-144, zinc-65, and gold-199 and the effects of radiation were followed on the hard clam, *Mercenaria mercenaria*, Linne; the oyster, *Crassostrea virginica*, Gmelin; and the bay scallop, *Aequipecten irradians*, Say. These animals were collected in the vicinity of the Radiobiological Laboratory and held in tanks of running sea water until used. All fouling organisms were cleaned from the shells prior to using the animals in experiments.

Cotton-filtered sea water having a salinity range from 29 to 35‰ and a temperature of 22 $\pm 2^{\circ}$C was used in all uptake experiments. The sea water for retention experiments was pumped directly from a source outside the laboratory; salinity and temperature varied with the tide and seasons.

Live animals were wrapped in polyethylene and measured for their contained radioactivity. Animal tissues were prepared for counting by rinsing in filtered sea water to remove loosely adsorbed surface activity. All radioactivity measurements were made with a well-type scintillation crystal attached to a conventional scaler. Size of the crystal used was determined by size of the animal. Radioactivity is reported as counts per minute per gram with appropriate corrections for geometry, background, and decay.

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Radionuclides may be grouped into two general classifications based on their origin. One includes fission products resulting from the splitting of the nucleus of the uranium atom or plutonium atom; the others are induced radionuclides formed by stable isotopes capturing neutrons. The radionuclides that occur from the fissioning of uranium are known, but induced radionuclides vary since they are isotopes of elements present in the area of the neutron flux. Some of these induced radionuclides have been found to be more important than the fission products as contaminants in radioactive wastes. Two of the fission products of concern in the oceans are cesium-137 and cerium-144. Zinc-65, which was found in marine fishes soon after the 1954 nuclear detonations in the Pacific, and gold-199 are two induced radionuclides that are discussed in this paper.

The rate of accumulation, levels of concentration, mode of entry, and assimilation of specific elements depend largely on their physical and chemical states in the medium and the physiological demands of organisms for the element. Elements and their radioisotopes are present in sea water either as particles or as ions. A radioisotope occuring in sea water in a particulate form may become associated with a molluscan shellfish by adsorption to its body surfaces or by ingestion into its digestive tract. Only a small quantity of the particulate nuclides may be retained as they pass through the digestive tract, since particles do not readily penetrate through semi-permeable membranes; however, the ionic radionuclides have little difficulty passing through tissue membranes and thus have the potential of being assimilated to higher levels.

CESIUM-137

Cesium is one of the alkali metals and is chemically similar to sodium, potassium, and rubidium (Hood and Comar, 1953). The radioisotope cesium-137 with a physical half-life of 30 ±3 years is found in sea water as a fission product chiefly in the ionic state. Cesium-137 is accumulated to relatively high levels by soft tissues of shellfish, thus making it an important radioactive contaminant since these soft parts are used as food by man.

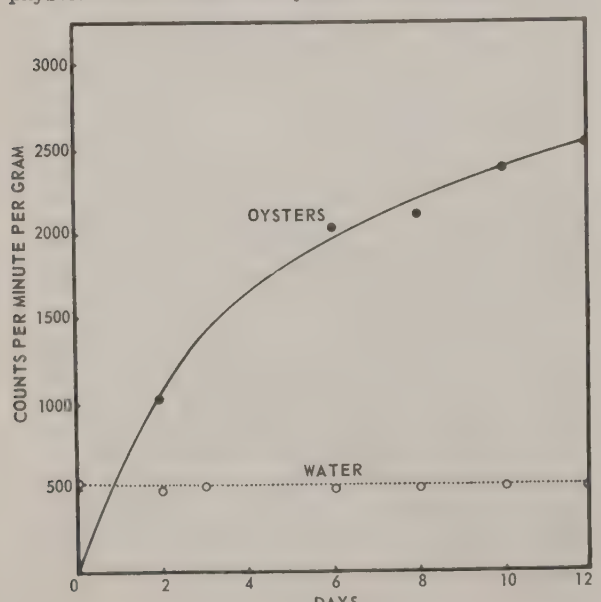

Figure 1. Uptake of Cs^{137} by oysters.

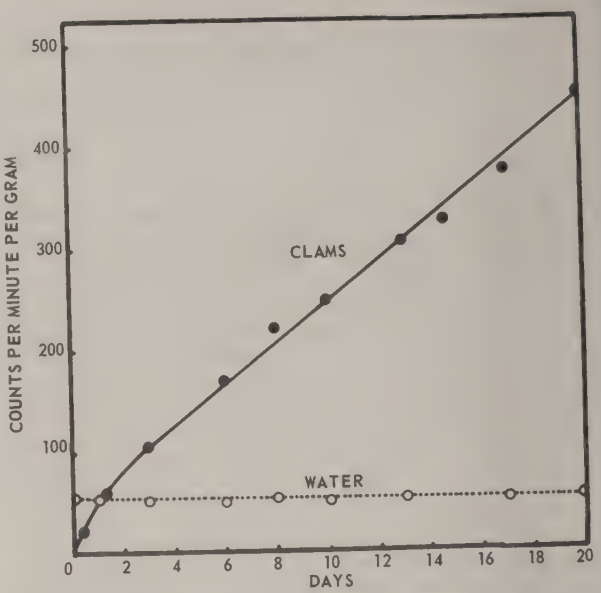

Figure 2. Uptake of Cs^{137} by hard clams.

Carrier-free cesium-137 was used as cesium chloride and was in secular equilibrium with its radioactive daughter product, barium-137. The time between sampling and measurement of activity was long enough for secular equilibrium to occur between the parent-daughter components, thus eliminating the effect of biological separation in the determination. The amount of cesium-137 that was accumulated or the concentration factor of this nuclide in the tissues of the animals was computed by dividing the activity per gram of animal or tissue by the activity per gram of sea water in which the animals were held.

The uptake of cesium-137 by oysters and clams is shown in Figures 1 and 2, respectively. Clams accumulated the radioisotope more than oysters. At the end of 20 days, the soft parts of the clams concentrated cesium-137 by a factor of six over the cesium-137 concentration in sea water. The clams were continuing the uptake of the isotope at the termination of the experiment, so it was not possible to determine the final concentration factor for clams. At the end of 12 days, the concentration factor of cesium-137 in the soft parts of the oysters was five; however, at that time the tissues of the oysters appeared to be entering into a steady state condition with the isotope.

It is necessary to determine the time required for biological elimination of the nuclides by molluscs, should they become polluted by radioactivity. This is essential to know so the shellfish will again be safe to use as food. The time required for a living tissue or organ or an individual to eliminate one-half of a given amount of substance through biological processes is referred to as the biological half-life. As an example, if a mollusc contains 1000 counts per

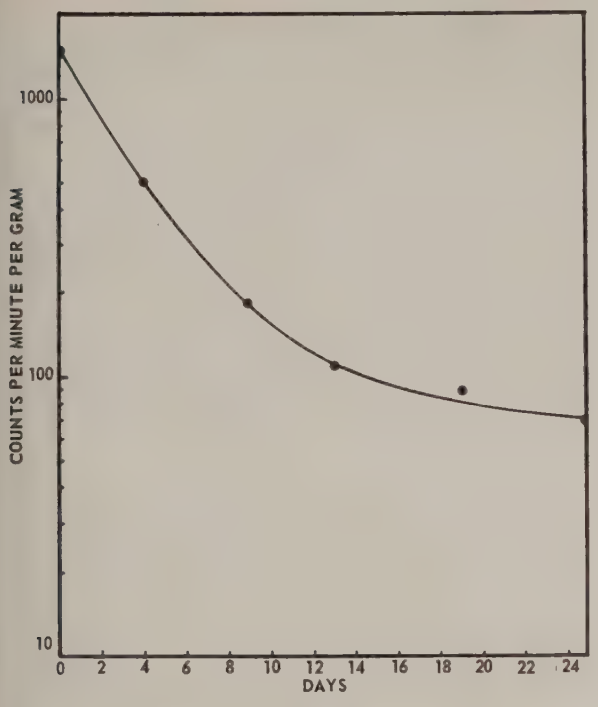

Figure 3. Loss of Cs^{137} by oysters.

minute initially and in 3 days the counts decrease to 500 counts per minute, this decrease of activity would give a biological half-life of 3 days for this particular animal and radionuclide.

Investigations were carried out to determine the loss of cesium-137 by oysters and clams (Figures 3 and 4). The soft tissues of oysters lost activity rapidly during the first 18 days, at which time the rate of loss decreased. After 25 days, only 4 percent of the total activity remained in the tissues. The loss of cesium-137 in clams was followed for 28 days. As

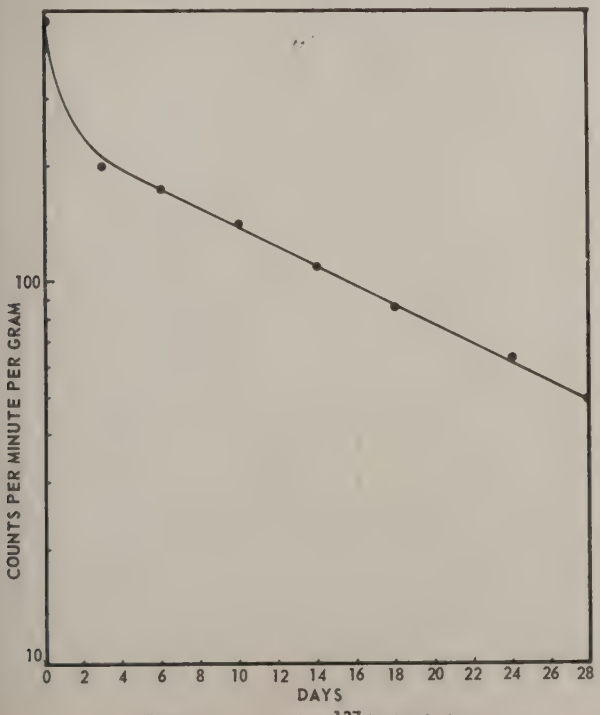

Figure 4. Loss of Cs^{137} by hard clams.

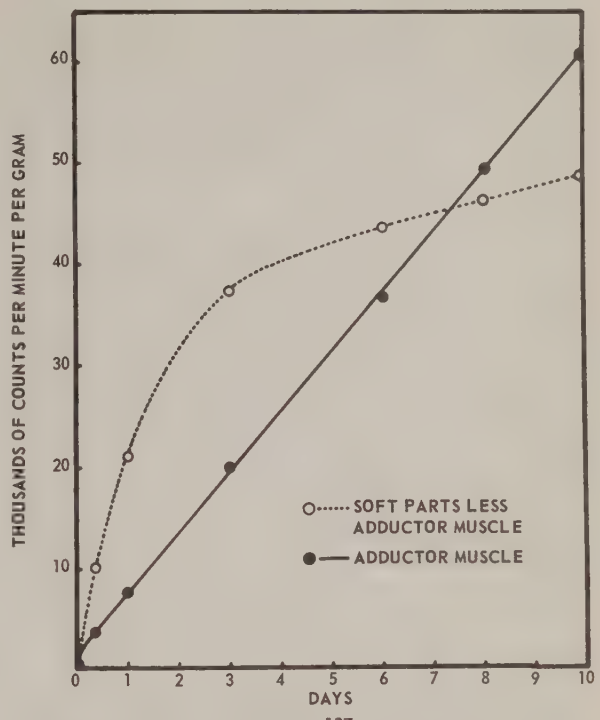

Figure 5. Uptake of Cs^{137} by bay scallops.

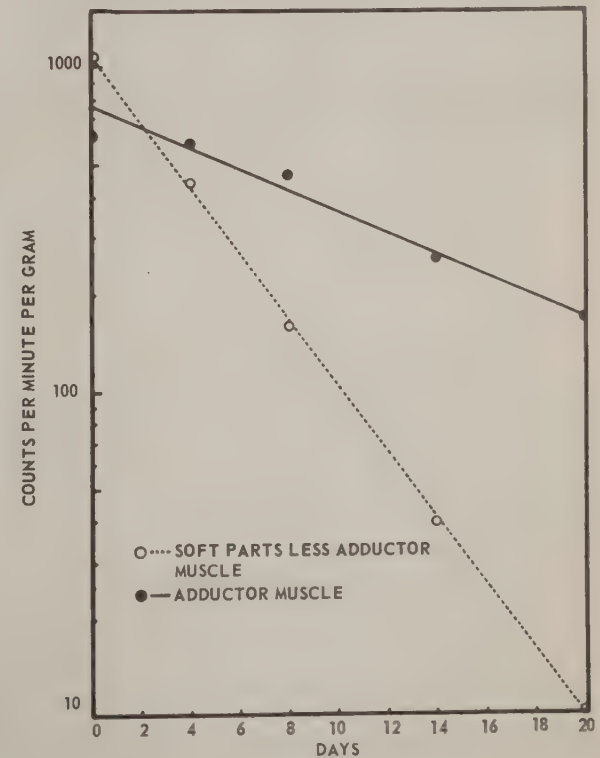

Figure 6. Loss of Cs^{137} by bay scallops.

with the oysters, a slower rate of loss occurred following the rapid initial loss. Twelve percent of the isotope remained in the clams after 28 days, which was higher than for the oysters after the same time interval. This residual activity remaining in the tissues of the clams and oysters was possibly the result of the nuclide becoming complexed in chemical compounds within the tissues.

Accumulation and loss of cesium-137 was interpreted as having been influenced by muscle and the remaining soft parts. Separate analyses of these two components were made of the uptake and loss of cesium-137 by the bay scallop. The adductor muscle of the scallop is the only portion used dietetically in this country. It is important to know the rates of uptake and loss of cesium-137 by this tissue. Radionuclides entered the tissues rapidly at first, with the final level being higher than that of clams (Figure 5). There was a more rapid uptake by the soft tissues other than muscle, but in time the highest concentrations were reached by the muscle. The concentration of cesium-137 in the muscle tissue after 10 days was 10 times that in sea water and steadily increased, while that in the visceral mass was concentrated 8 times and leveled off. It is apparent that muscle is the higher concentrator of the nuclide.

The visceral mass of the scallop lost cesium-137 faster than the adductor muscle (Figure 6). After 20 days, 25 percent of the activity remained in the muscle while only 8 percent remained in the visceral mass. The biological half-life of cesium-137 in the muscle was 13 days and in the visceral mass 3 days. It is noted that the line illustrating the loss of activity by the muscle is a regression line of anti-logarithms of the counts.

The different rates of uptake and loss of cesium-137 by the muscle tissue and visceral mass of the scallop indicate how these two components influence uptake and loss of this nuclide in an organism. This relationship is a rapid initial uptake or loss as influenced by the visceral mass, and then a longer continuous uptake or loss as influenced by the muscle tissue.

CERIUM-144

The physical state of a fission product in sea water controls to a great extent its mode of entry and subsequent assimilation by marine organisms. Greendale and Ballou (1954) determined the physical states of fission product elements in sea water by simulating an underwater bomb detonation. They found for cerium-144 that approximately 2 percent was ionic, 4 percent collodial, and 94 percent particulate. This large amount of cerium-144 in sea water in particles influences availability of this radioisotope to molluscan shellfish, as evidenced in the following experiments.

The concentration of cerium-144 by tissues of clams and oysters was determined when the nuclide was available to the animals as particles in the medium or associated with known populations of *Nitzschia closterium* cells. Cells from 1 liter of culture were fed daily to the animals. To maintain optimum volume of water to animal ratios as clams and oysters were removed for sampling, both the cell populations and the volume of medium containing the cells to be fed the animals were decreased proportionally. The uptake of the radionuclide was slow and continuous through the tenth day, after which it fluctuated in the tissues for the remaining 12 days of the experiment. The clams reached their maximum levels of accumulation after 20 days, with 23 percent of that made available daily being accumulated. It is assumed that the remainder of the cerium-144 available during the experiment adsorbed to the shells of the clams and oysters and to the container, as water samples taken before changing the medium each day did not contain any significant amounts of cerium-144.

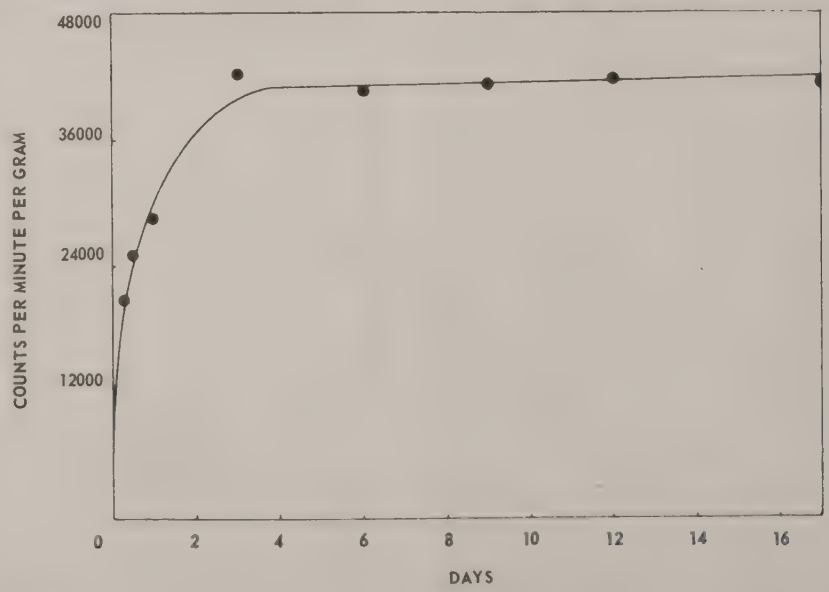

Figure 7. Uptake of cerium-144 from water by clams.

In experiments on the uptake of cerium-144 by clams, the animals were not sacrificed but were periodically removed from the radioactive water long enough for the activity in the entire animal to be measured. This method of repeatedly determining activity in the same animal throughout an experiment decreases effects of individual variations. Initially uptake of the radionuclide was rapid, but began to decrease on the third day (Figure 7). This diminished rate of uptake was undoubtedly caused by a decrease in the availability of cerium-144 in the water. Only 11 percent of the original activity remained in the water after 3 days and upon termination of the experiment after 12 days only 4 percent remained in solution. This removal of the nuclide from solution affected the availability of the isotope to the clams, and thus possibly influenced the levels to which cerium-144 was accumulated.

Investigations were carried out to determine cerium-144 uptake and distribution by shell, liquor, and meats of the clams. Animals were removed periodically, dissected, and the activity in the three components was determined. Shells contained the highest level of activity, followed by meats, and liquor (Figure 8). Radioactivity of the shell was largely surface adsorption of cerium-144, while activity associated with the meats was possibly the effects of particles adhering to tissue surfaces and present in organs and structures connected with the digestive tract. Only a small percentage may be assimilated since particle size would be a limiting factor in their absorption through the walls of the intestinal tract.

It is essential to know the time required for biological elimination of radioactive pollutants by molluscs to conclude when they again will be available as food for man. To understand the metabolic role of cerium-144 more fully, the following experiments were conducted with special emphasis on long term retention and whole animal counting. To determine

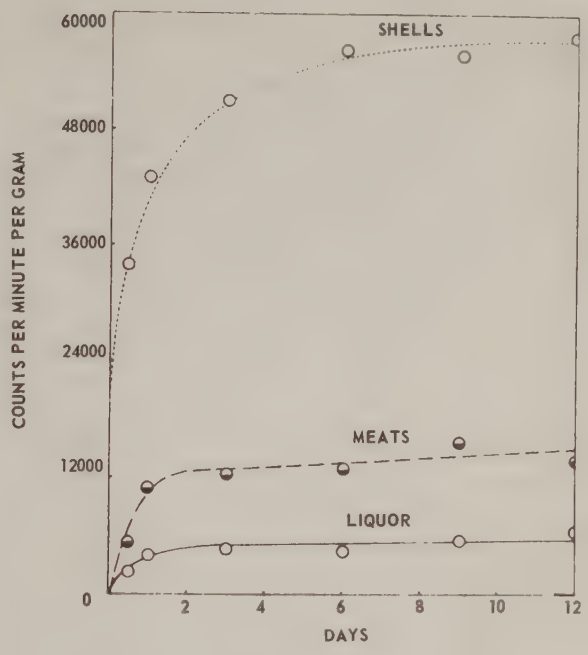

Figure 8. Uptake of cerium-144 by component parts of clams.

the rate of loss by clams, they were immersed in cotton-filtered sea water containing cerium-144 and after a suitable time were transferred to tanks of rapidly flowing sea water. The initial loss of cerium-144 was rapid during the first 45 days, after which the loss was reduced (Figure 9). Cerium-144 remaining after 195 days represented 20 percent of the original activity in the animals. It is possible that activity remaining at this time is either complexed by the metabolic processes of the animals or securely adsorbed to body surfaces.

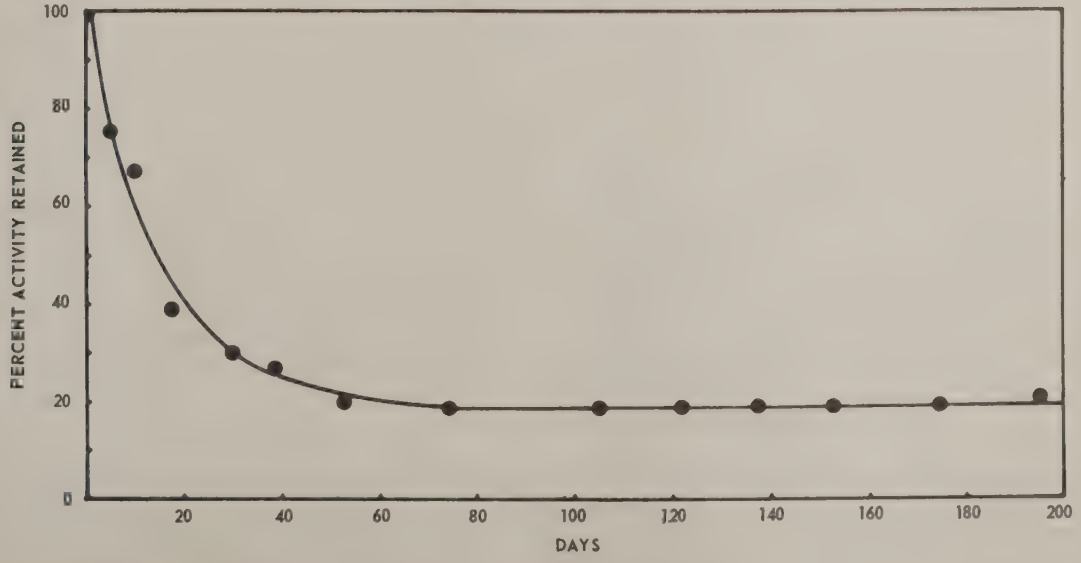

Figure 9. Loss of Ce^{144} by the hard clam.

The rate of loss of cerium-144 by the bay scallop was observed for 35 days. The animals were removed from sea water and separated into shell, visceral mass, and adductor muscle. The loss of the radionuclide in all three tissues was rapid in the beginning, followed by a reduction in the rate of loss (Figure 10). After 35 days, the shells had lost 55 percent of the original activity; muscle, 62 percent; and the visceral mass, 89 percent. It appeared that any further loss of activity from these three components would be small.

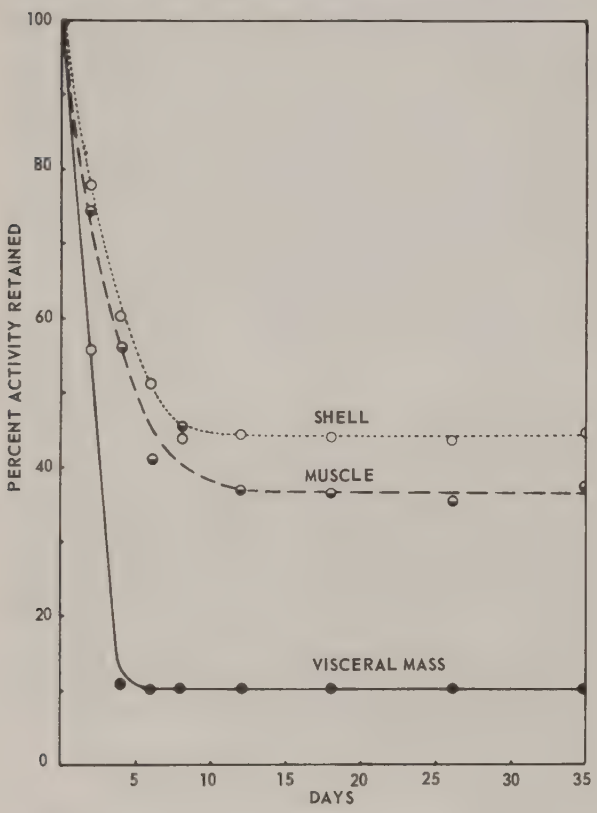

Figure 10. Loss of Ce^{144} by components of the bay scallop.

ZINC-65

In the past most data on uptake, accumulation, and loss of radionuclides by marine organisms has concerned single species held in confined volumes of water. This is not a very satisfactory manner of determining the relationship that would exist between the radioactivity of the water and that of the organism in nature, since the volume of water per organism would be a controlling factor of the experiment. If five animals are placed in ten liters of water and remove a large amount of the activity, they will have a higher concentration factor than would have occurred if ten animals had been placed in the same volume of water. Thus, sufficient volumes of water should be used to minimize the effects of animals drastically reducing activity in it. Results of our tank experiments reveal not only the effects of contamination on an entire community, but also permit evaluation of an individual in relation to the ecosystem. By increasing the volume of water in an experiment, it is possible to conduct experiments of long duration due to the improved physiological condition of the organisms; thus both chronic and acute contamination can be investigated.

The universal occurrence of zinc in all living matter and its role as an essential nutrient for plants and animals is firmly established (Vallee, 1959). The presence of zinc-65 in marine organisms from the Pacific Ocean following nuclear test detonations has been reported by Seymour *et al.*, 1957; Lowman, Palumbo, and South, 1957; and Welander, 1957. This neutron-induced radionuclide is produced by nuclear changes of the stable element and occurs in marine waters principally in the ionic state. Zinc-65 can also be introduced into the oceans as part of corrosion products present in the coolant water of nuclear reactors.

Molluscs in general have a higher zinc content than other invertebrate groups (Vinogradov, 1953). Thus, these shellfish are important as transfer organisms of zinc-65 through food webs to man. The uptake and accumulation of zinc-65 by oysters and clams was followed in an experimental environment consisting of 1200 liters of cotton-filtered sea water continuously circulated in a fiberglass tank. Enough carrier-free zinc-65 was added to the water to give a concentration of 8×10^{-5} microcuries per milliliter. The animals were removed periodically for counting and then returned to the radioactive medium. A conversion factor was needed to compensate for differences in geometry

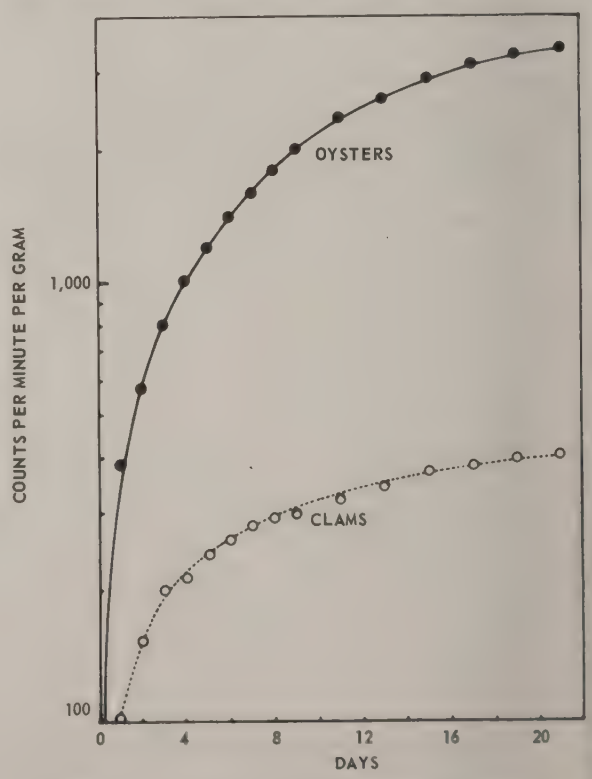

Figure 11. Accumulation of Zn^{65} by oysters and clams in an experimental marine environment.

encountered in comparing activity in the animals and in the water. This factor was derived by first measuring the activity in the animals directly in a whole animal counter, secondly, digesting the animals in acid, and finally diluting to the same volume as that of the sea water that was measured for activity. An average of three measurements yielded a factor of 0.77; that is, the sample counted 23 percent less when dispersed in water, which was possibly the result of the shielding effect of the water. Clams accumulated zinc-65 at a slower rate than oysters on a unit weight basis (Figure 11). At the completion of the experiment, however, it was observed that these two curves if extrapolated would continue upward, indicating a gradual but reduced uptake of zinc-65 in both clams and oysters. Thus, oysters concentrate zinc-65 to higher levels than clams. This increased amount of zinc-65 in oysters was possibly caused by a greater physiological demand for this element than clams, as is indicated by the natural zinc content of these two animals.

GOLD-199

Molluscan shellfish are particularly susceptible to contamination by tagged radioactive sediments, since these animals inhabit the bottom of estuaries and feed by filtering particles from large volumes of water. Radioisotopes such as gold-199 have been utilized as tracers in estuarine waters to determine the movements of these sediments (Krome, 1960). Gold-199 was the isotope of choice because of its short half-life, adsorptive power, and detectability.

To investigate uptake and accumulation of gold-199, clams and their separated shells were placed in radioactive water. Another group of clams was placed in bowls containing montmorillonite clay and these were immersed in the sea water. The clams and separated shells in the water were removed periodically to determine their radioactive content, while those in clay were counted at the end of the experiment so as not to disturb the substrata.

The uptake of activity by both clams and shells was rapid during the first 14 days, followed by a much slower rate of uptake throughout the remaining time of the experiment (Figure 12). Clams contained 3.6 times as much activity than shells upon termination of the experiment. This difference was shown to be significant through a comparison of means by a t-test. The higher concentration in the clams was apparently the result of adsorption of the nuclide to their body surfaces and possibly some contribution from metabolic processes. The clams in the montmorillonite clay contained 38 percent less activity after 23 days than those in the water. This lower activity conceivably was caused by the clams burrowing in the clay, preventing them from obtaining as much activity as those in the active water.

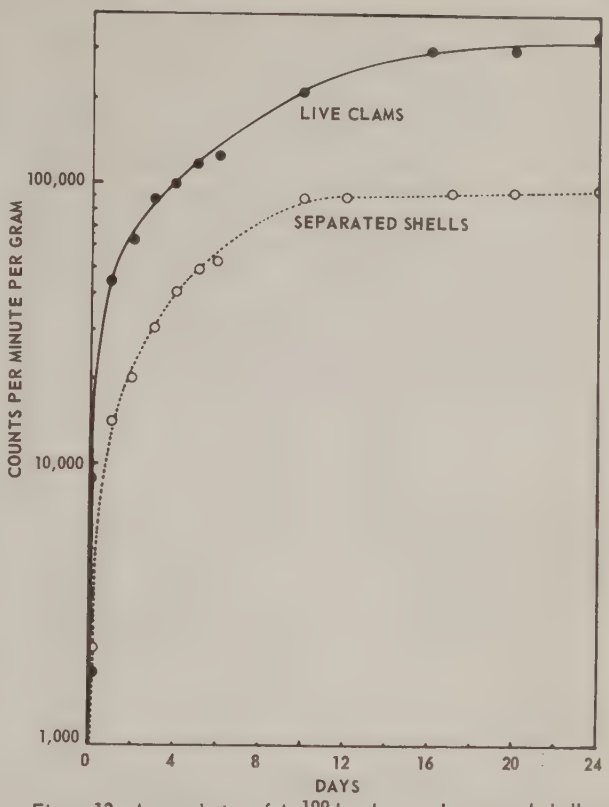

Figure 12. Accumulation of Au^{199} by clams and separated shells.

RADIATION EFFECTS

The importance of the effects of ionizing radiations on marine organisms has increased since the oceans have become a convenient area in which to dispose of radioactive waste materials and to test nuclear weapons. This potentially harmful radiation may originate either from the fission process itself or from ingested by-products of the fission process. Thus, a reduction of harvestable living resources of the sea could conceivably occur from the effects of atomic radiations on organisms that are utilized in commercial fisheries or by a reduction in those fish that are utilized as food by these economic species.

The following experiments were undertaken to determine the lethal doses at which 50 percent (LD_{50}) of the oysters and clams died.

All animals were irradiated with a cobalt-60 source with a dose rate of 350,000 roentgens (r) per hour. The radiation chamber was a cylindrical cavity 6 inches in diameter by 8-1/2 inches high. Polyethylene containers were used to hold the animals while being irradiated. After irradiation the animals were returned to tanks of rapidly flowing sea water where daily checks were made for mortalities.

Fifty animals composed each group receiving the different dosages of radiation. Oysters were exposed to 5,833; 11,666; 23,332; 46,664; 93,328 and 186,656 roentgens. Irradiation of clams was in similar groups except for three groups irradiated at 116,600, 139,992; and 163,324 roentgens.

The cumulative mortality of the various groups of clams is shown in figure 13. There were no mortalities in the control groups of clams or oysters. The LD_{50} for clams in the various dose groups are: 186,656 r - 5.5 days; 163,324 r - 4.5 days; 139,992

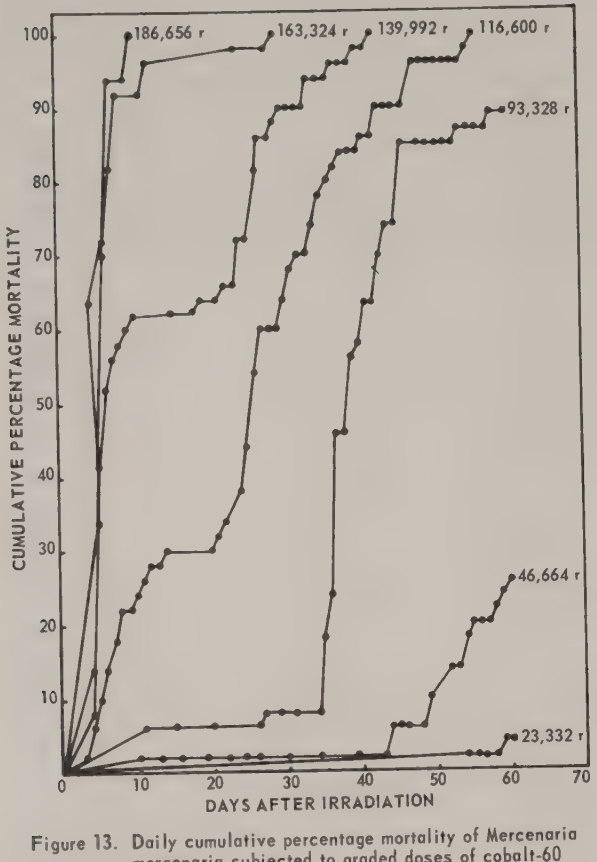

Figure 13. Daily cumulative percentage mortality of Mercenaria mercenaria subjected to graded doses of cobalt-60 gamma radiation. (No mortalities in control).

r - 6.5 days; 116,600 r - 25.5 days; 93,328 r - 38.5 days. The remaining groups of irradiated clams had not attained a 50 percent mortality after 60 days.

The LD_{50} for oysters (Figure 14) in the various radiation groups is: 186,656 r - 26 days; 93,328 r - 34 days; 46,664 r - 36.5 days; 23,332 r - 35 days; 11,666 r - 40 days; and 5,833 r - 48 days.

The physical state of materials introduced into the sea controls the role they play in the metabolism of marine animals. Radioactive contaminants occur either as particles or in solution. Particles may go into solution depending on the physical and chemical properties of a particular body of water. The dissolved substances may be precipitated as particles of colloidal or larger size either by co-precipitation with other elements, by sorption on organic or inorganic particles already in the sea, or by interaction with other sea-water constituents. Thus, both dissolved materials and particles may be ingested by organisms and enter into the biochemical cycle.

Availability of radionuclides for uptake by shellfish is dependent in part on the chemical nature and physical state of the nuclides when present in sea water. Radionuclides can further be categorized according to the methods by which they are produced, that is whether they are products of the fission processes or neutron-induced. The four radioisotopes used in these investigations thus have the

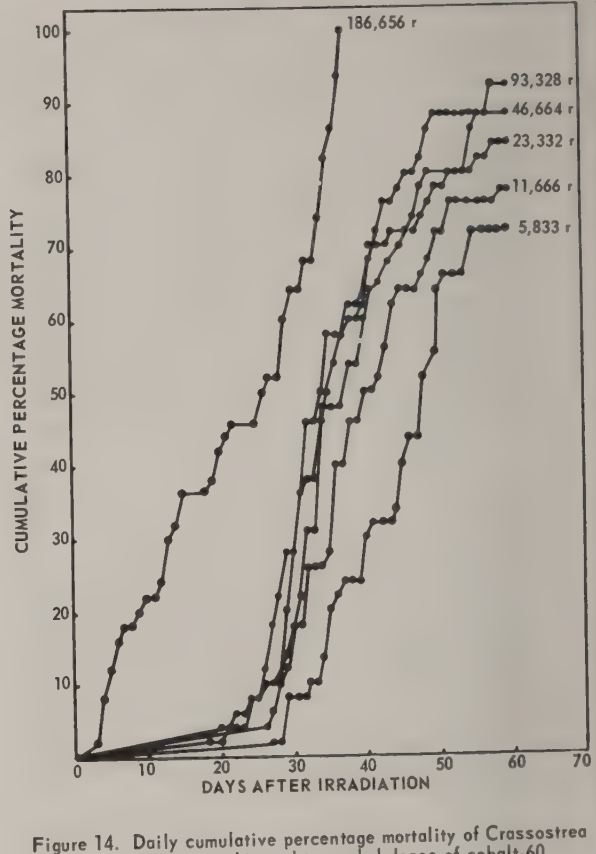

Figure 14. Daily cumulative percentage mortality of Crassostrea virginica subjected to graded doses of cobalt-60 gamma radiation. (No mortalities in control).

following classifications: Cesium-137, ionic; cerium-144, particulate (both fission products); zinc-65, ionic; gold-199, particulate (both induced radionuclides). Given data indicate that the uptake of all the nuclides by these molluscs was basically the same, an initial rapid acceptance of the element followed by a continued but reduced rate of uptake. This initial rapid uptake appears to be a combination of physical adsorption on body surfaces and metabolic processes of the animals. The later, continued reduced rate of uptake is an effect of the animals' metabolic action, since saturation has now been achieved through sorption. Loss of these four nuclides showed a similar pattern as that of the uptake.

Organisms take up from their environment and food and incorporate into their bodies the elements needed for their maintenance, growth, and reproduction. The proportions of the essential elements required by organisms are different from the proportions in the environment. This results in concentrations of some elements in the biosphere. Molluscs differ in their uptake of the four isotopes mentioned. The concentration factor of an element has already been defined as the amount of an element in an organism in ratio to the quantity in an equal weight of water. Concentration factors vary with season, with the concentration of an element in water, with the concentration of other metabolically similar elements, with the age

of an organism, and with a number of other such factors. Also, the concentration of a nuclide depends both upon the metabolic need of the particular organism for the element, and the tissue preference of the nuclide. Cesium-137 is accumulated to relatively high levels by the soft tissues other than muscle, but in time the highest concentrations are reached by the muscle. It was found that clams concentrated cesium-137 to a higher level than oysters, which is in agreement with the differences in their body structure as regards muscle tissue.

Whether or not the radionuclide occurred in the ionic or particulate state in sea water made little difference in its uptake by the three groups of shellfish. If the particulate radionuclides cannot be metabolized by the animals they may adsorb to body surfaces or associate with the organs and structures connected with the digestive tract. Such an accumulation of radioactive particles may be important for purposes of passage through food webs to man. The fact that the adductor muscle of scallops and all the soft tissues of oysters and clams are eaten allows for the ingestion of many radionuclides that may not be metabolized and incorporated into the tissues of these shellfish. Many nuclides are concentrated by the shells of these animals. Accumulation of radioactivity by shells may be important since they are placed on the bottom by oystermen as cultch to which the young oyster spat attaches; they are also used in many other industries.

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Movements of Hatchery-Reared Lake Trout in Lake Superior[1,2]

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ABSTRACT

The history of stocking of lake trout (*Salvelinus namaycush*) in the Great Lakes is reviewed.

The study of movements is based on capture of 24,275 fin-clipped lake trout taken in experimental gill nets and trawls and commercial gill nets.

Yearling lake trout planted from shore dispersed to 15-fath (27-m) depths in 3½ hr. Most fish remained within 2 miles (3.2 km) of the planting site 2 months, but within 4 months some fish had moved as much as 17 miles (27 km). The highest abundance of planted lake trout was in areas 2–4 miles (3.2–6.4 km) from the planting site even 3 years after release. Distance moved and size of fish were not correlated.

Dispersal of lake trout begins at planting and probably continues until the fish are mature. Most movement was eastward in southern Lake Superior and followed the counterclockwise surface currents. Movement is most rapid in areas of strong currents and slowest in areas of weak currents or eddies. Movement to areas west of the Keweenaw Peninsula was insignificant from plantings in Keweenaw Bay and nil from other plantings farther east. Lake trout planted in the eastern third of the lake dispersed more randomly than those planted farther west. Few fish moved farther offshore than the 50-fath (91-m) contour. Lake trout planted in Canadian waters made insignificant contributions to populations in US waters.

INTRODUCTION

Prior to the mid 1930s, millions of lake trout (*Salvelinus namaycush*) fry were stocked annually in the Great Lakes in the belief that, somehow, hatchery production was superior to natural reproduction. Lake trout stocking was largely abandoned in the 1930s because evidence of effectiveness of the practice was lacking (Dymond, 1957). The extreme reduction or near extinction of lake trout stocks caused by depredations of the sea lamprey (*Petromyzon marinus*) in the upper Great Lakes forced reconsideration of stocking as a method of maintaining abundance or of re-establishing populations. Because potential sources of lake trout eggs in inland lakes were either small or were in remote areas, stocking of millions of fry could no longer be considered. Attention was directed, therefore, to rearing lake trout to sizes or ages where chances of

[1]Received for publication October 8, 1964.
[2]Materials in this report were the basis of a talk by Pycha at the Annual Meeting of the American Fisheries Society, Atlantic City, New Jersey, September 15, 1964.

J. Fish. Res. Bd. Canada, 22(4), 1965.
Printed in Canada.

survival might be good. A series of large-scale experimental plantings, most of which involved interagency co-operation, was begun in 1944 and has continued to the present.

By the late 1950s, experimental plantings of 9- to 37-month-old lake trout indicated that fish 16–18 months old should yield the highest survival consistent with rearing costs. So long as the sea lamprey was uncontrolled, no reliable information could be obtained on average survival rates — only relative survival of fish planted at various sizes or ages was known. Nevertheless, the critical state of the fishery and the lake trout population in Lake Superior demanded intensive stocking as soon as a means of controlling the sea lamprey was available.

The discovery of a chemical that selectively kills all year-classes of sea lamprey larvae in the streams, and the decision of the Great Lakes Fishery Commission to begin treatment in 1958 of all lamprey-producing streams tributary to Lake Superior, improved greatly the prospects for profitable stocking. Rearing and planting of yearling lake trout were intensified. The Michigan Department of Conservation had developed methods of holding lake trout brood stock and was able to supply enough eggs for the rearing facilities of all US agencies by 1962. Increased research by both Canadian and US agencies included evaluation of the success of stocking as one of the principal objectives.

In 1947–61, a total of 5,730,000 fin-clipped lake trout was planted in Lake Superior in a total of 51 separate plantings. Of these, slightly over 1 million were fingerlings planted in the fall (most of the fingerlings were planted prior to 1955) and about 50,000 were 2- or 3-year-old fish. The remainder were yearlings, 15–17 months old, planted in the spring. Prior to 1960, most of the fish were planted from boats in water 15–20 fath deep within a few miles of shore. Few plantings in US waters were spread over wide areas. A few Canadian plantings were made from aircraft. In 1960, two large plantings were released directly from shore in areas within 1 mile of water 15 fath deep. Since 1960, nearly all plantings in US waters have been released from shore. Prior to 1956, some fin marks were repeated in consecutive years, but since then no mark has been used more than once in 2 years.

Knowledge of the movements of planted lake trout is necessary for evaluation of survival of planted fish or of the relative success of various planting practices. Because the objective of stocking lake trout is to re-establish naturally reproducing populations in all areas formerly occupied by lake trout in the Great Lakes, the extent of movement may determine where lake trout must be planted. This report reviews earlier studies on movements of marked lake trout, both hatchery-reared and native in the Great Lakes, summarizes the studies on dispersal of small planted lake trout done by the Bureau of Commercial Fisheries research vessel *Siscowet*, and describes the movements of lake trout planted at various locations in US waters of Lake Superior in 1952–61.

MATERIALS AND METHODS

This study is based on 436 fin-clipped lake trout caught in experimental gill nets, 2338 captured in experimental trawls, and 21,501 taken in $4\frac{1}{2}$-inch-mesh (114-mm), extension measure, gill nets by commercial fishermen. The gear was not specified for 52 fish from north shore and offshore waters of Ontario.

Using the research vessel *Siscowet*, we obtained information on the abundance, distribution, and movements of juvenile lake trout in 1958–63. Experimental fishing was done at several locations among the Apostle Islands and in Keweenaw Bay (Fig. 1). Experimental gill nets — each 300 ft (91m) long and 6 ft (1.8 m) deep, of 1–5-inch (25.4–127-mm) mesh by $\frac{1}{2}$-inch (12.7-mm) intervals; and bottom trawls, 31-ft (9.4-m) semiballoon, of $2\frac{1}{2}$-inch-mesh (63.5-mm) body, and $\frac{1}{2}$-inch-mesh (12.7-mm) codend — were fished at various depths at each location. The gill nets usually were fished 1 night and the trawls towed 15 min. Total length (inches) was recorded for each fin-clipped fish. Of the lake trout captured in trawls, 102 fish taken at Frog Bay only a few hours after release were not included in the records of Table I. Observations in Keweenaw Bay were based on 431 fish taken in trawls.

Information on catches of fin-clipped lake trout from the Wisconsin commercial fishery was collected in 1959–62 by both the Wisconsin Conservation Department and the Bureau of Commercial Fisheries. Wisconsin personnel accompanied commercial fishermen and checked their catches until the season was closed on June 30, 1962. For the remainder of 1962 the Department used its own boat and employed fishermen to fish in the same manner as in previous

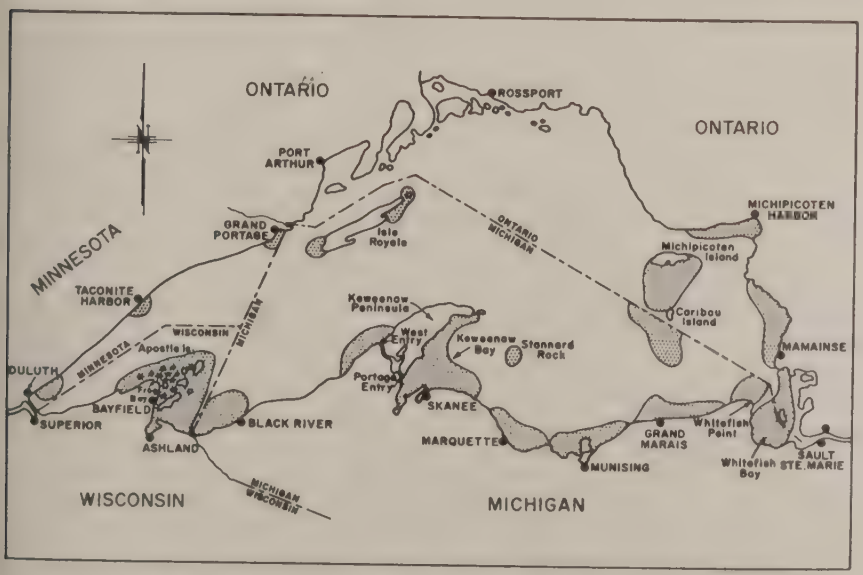

FIG. 1. Areas (stippled enclosures) of Lake Superior from which samples were obtained.

TABLE I. Number of hatchery-reared lake trout captured per hour of trawling according to time out and distance traveled (total numbers of fish captured are in parentheses; 1 mile = 1.609 km).

Months after planting	Distance from nearest planting site (*miles*)				
	<2	2–4	5–7	8–10	10–30
<3	19.6 (49)	2.8 (11)	4.7 (13)	1.6 (7)	0.0 (0)
3–4	32.5 (138)	49.4 (247)	5.5 (11)	2.3 (9)	0.6 (1)
5–7	16.0 (12)	29.9 (299)	7.2 (9)	4.0 (4)	1.3 (5)
12–14	9.0 (36)	25.3 (417)	7.8 (49)	9.1 (41)	3.3 (34)
15–16	3.7 (12)	32.7 (180)	10.8 (62)	6.3 (36)	1.1 (2)
17–18	12.0 (3)	14.0 (105)	4.0 (3)	6.0 (6)	2.3 (4)

years. The Bureau employed one Wisconsin commercial fisherman to keep complete records of his catch. This fisherman also fished off Black River in Michigan.

All data from Michigan waters were collected by the Bureau in 1959–63. In March 1959, nine of the most productive commercial fishermen in Michigan were employed to collect data from their own catches. Most of these fishermen have provided data regularly since that time. (A limited amount of fishing was allowed under contract to the Bureau after the season closure.)

Data from Ontario waters of eastern Lake Superior, available only for 1961 and 1963, were provided by the Fisheries Research Board of Canada, Biological Station, London, Ontario. Information was collected by both fishery technicians and commercial fishermen employed by the Board.

The Minnesota Department of Conservation provided data collected by commercial fishermen operating under special permits in 1963.

All agencies collected essentially the same information. Each fish caught was examined for clipped fins and lamprey wounds and scars. Scale samples and measurements were collected from entire catches or net-run samples according to schedules established by the agencies. All fin-clipped fish were measured. The amount of gear fished, location of the set, and number and total weight of fish caught were recorded for each lift.

In Wisconsin, 12.3–21.2% of the total commercial production of lake trout was sampled each year in 1959–62. The Bureau's samples comprised 27.9–47.9% of the total Michigan production in the same years. Since the closure of the lake trout season in mid 1962, all commercial production of lake trout in US waters has been monitored.

TABLE II. Average length (inches) of hatchery-reared lake trout in the Apostle Islands region, arranged according to distance traveled and time at liberty. (Number of fish in parentheses; 1 inch = 25.4 mm; 1 mile = 1.609 km.)

Months at liberty	Distance from nearest planting site (*miles*)				
	<2	2–4	5–7	8–10	10–30
12–14[a]	8.1 (8)	7.9 (278)	8.2 (30)	7.9 (8)	8.1 (23)
24–26[b]	... ..	11.6 (77)	... ...	11.7 (172)	... ...
36–38[c]	... ...	13.8 (76)	... ...	13.9 (111)	... ...

[a]Based on trawl catches of lake trout planted in 1962.
[b]Based on gill net catches of lake trout planted in 1961.
[c]Based on gill net catches of lake trout planted in 1960.

The areas from which data were collected (Fig. 1) included all important lake trout fishing grounds in US waters in 1959–63. Samples were well distributed throughout the areas. Most of the data used in this report came from the areas along the south shore. The number of fin-clipped fish caught in these areas was substantial and complete information on fishing effort was available. The other areas indicated in Fig. 1 provided more limited information because data were not available for an unbroken series of years, the catch of fin-clipped fish was low, or information on fishing effort was lacking.

Although fin-clipped lake trout were planted in Lake Superior every year in 1952–61 (except 1957), the materials in this report are limited, with two exceptions, to returns of fish from plantings that had distinctive marks not used elsewhere. Two marks were repeated in other areas, but were used for year-classes 4 and 6 years apart, and these fish could easily be distinguished by size alone. Summaries of returns from all plantings were made from data collected in 1959–62. Complete 1963 data available at the time of writing for four Michigan plantings were also included.

Returns of fin-clipped lake trout were assigned to given plants by one or more criteria. Nearly half the fish bore fin-clip combinations which were used only once and could not be confused with fish from other plantings, but those planted in the Apostle Islands in 1952–54, 1956, and 1958 all bore the same mark. Young fish bearing fin marks which were not used more often than once in 2 years could be identified from the fin mark and the length of the fish; but within 2 or 3 years after release the lengths of individuals from a plant were so variable that some could be identified only after ages were determined from scales. The ages of fish in a subsample of fin-clipped trout were applied by length groups to the samples of fish bearing the same mark to obtain estimates of the number recaptured from each planting. Fish recaptured from the 1952–54 plantings in the Apostle Islands, all of which bore the same fin mark, were

assigned arbitrarily to 1954; examinations of scales indicated insignificant numbers of returns from fish stocked in 1952 and 1953.

Ages were determined from plastic impressions of the scales of 1538 fish that bore the fin mark of those planted in the Apostle Islands prior to 1960. Impressions were made with a modified jewelers press (Smith, 1954), and were read at a magnification of 83× on a microprojector. Most scales of hatchery-reared lake trout could be read accurately, but age determinations were occasionally complicated by the frequent presence of two marks in close proximity, either one of which could have been the first annulus. Although it is possible the first mark was the "0-mark" described by Cable (1956), it is believed that more probably the second mark was an accessory check laid down at the time the fish was planted. Because the only groups for which age determinations were necessary were planted at 2-year intervals, the presence of an accessory mark caused little difficulty in assigning fish to their respective plantings.

Nearly all data used in this study came from catches of fish planted in the spring as yearlings. Returns from plantings of fall fingerlings in the Apostle Islands in 1952–53 were included in Table III and Fig. 2 but were not used elsewhere.

TABLE III. Location and number of recoveries of hatchery-reared lake trout planted in various areas of Lake Superior.

Area of capture	Area of planting					Total
	Apostle Islands	Keweenaw Bay	Marquette	Munising	Whitefish Bay	
South shore Apostle Islands	8,210	1	0	0	0	8,211
Black River	340	0	0	0	0	340
West Entry	1,366	13	0	0	0	1,379
Keweenaw Bay	1,117	3,282	990	108	14	5,511
Marquette	137	55	292	303	9	796
Munising	416	100	264	1,411	55	2,246
Grand Marais	186	5	20	315	301	827
Whitefish Point	19	3	5	2	71	100
Whitefish Bay	5	0	1	0	1,865	1,871
East shore Mamainse	14	0	8	0	150	172
North shore and offshore	47	0	1	0	52	100
Total:	11,857	3,459	1,581	2,139	2,517	21,553

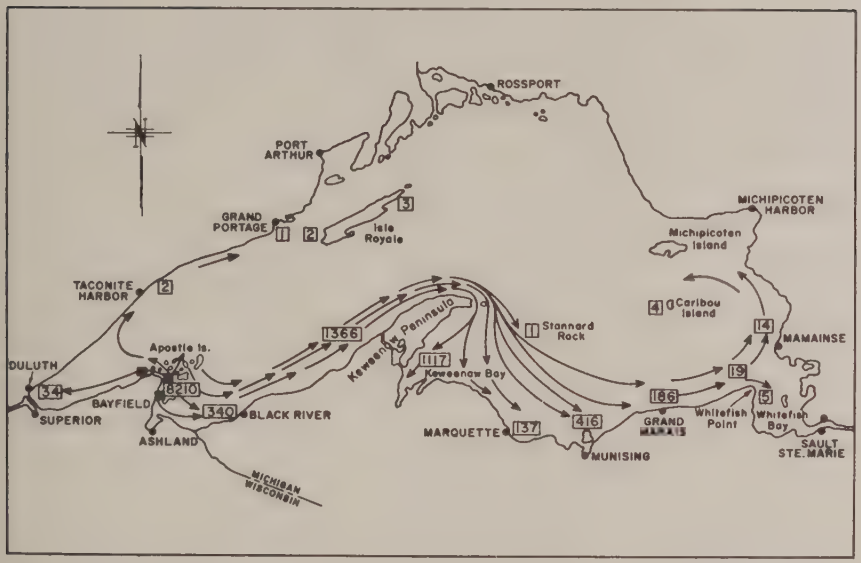

FIG. 2. Localities and number of returns of hatchery-reared lake trout planted in the Apostle Islands. Black squares are planting localities and open rectangles give the number of fish caught in each area; arrows indicate direction of movement.

The data on catch of fin-clipped fish per unit effort were based on lifts of approximately 50 million ft (15.2 million m) of $4\frac{1}{2}$-inch-mesh (114-mm) gill nets (braided nylon material). The average length of a gang of gill nets in a lift was roughly 15,000 ft (4572 m).

The map of surface currents of Lake Superior (Fig. 7) is a modification of a chart published by Harrington (1895). The original has been changed somewhat, according to recent findings of the Bureau's Biological Laboratory at Ann Arbor, Michigan. Some of the laboratory's data were included in Beeton *et al.* (1959). Additional unpublished records were obtained from the laboratory files.

POSSIBLE SOURCES OF BIAS OR ERROR

Analyses based on records of catch per unit effort (CPE) of individual fishermen are susceptible to several possible sources of bias. Differences in efficiency of the fishermen in the various areas is the most obvious. The fishermen in operation on Lake Superior in 1959–62 were the survivors of economic attrition through most of the 1950s. As abundance of lake trout declined, only the efficient operators were able to continue fishing. The efficiency of fishermen whose catches were sampled undoubtedly varied somewhat, but differences were minimized by earlier attrition of the less efficient. The gear used by all fishermen was practically identical.

Differential movement of various size groups within a year-class of planted fish or differential growth rates resulting from movement to other areas could

bias the data strongly. The fish of any planting caught in areas away from the planting site were usually grouped closely around the modal size for the group in the area where the fish were planted. Both the largest and smallest fish of a year-class in any one year were usually caught in the area where they were planted. Bias due to differential movement of various size groups or to different growth rates in the various sampling areas appears to have been inconsequential.

Differential mortality of lake trout in various areas could affect apparent movement. The sea lamprey invaded Lake Superior from the east end and reduced abundance of lake trout in the eastern part of the lake earlier than in the western end. By 1957 or 1958, lamprey activity (estimated from catches of lampreys in spawning streams and from the incidence of wounds on lake trout) was roughly equal in all areas along the south shore. In 1962–63, the incidence of lamprey wounds declined in all areas, but the most drastic decline was in the western end of the lake. Differential mortality of lake trout due to lamprey predation would lead to underestimates of the extent of movement eastward from the Apostle Islands, but this bias probably applies only to the Apostle Islands plantings of 1952–54. Lake trout appeared to be immune to lamprey attack for the first 2 or 3 years after release.

The bulk of the fishing effort in most areas was exerted in the spring and fall, the times of the year when fishing success was highest. Fishing was done only in the spring, when fishing was best, at Black River and in Whitefish Bay. Much of the fishing off West Entry was in the summer and early fall, when fishing was poor. The data of Tables IV and V, therefore, are biased toward overly high values at Black River and Whitefish Bay and low values at West Entry.

The possibility of chance error for average CPE values varies with the amount of gear lifted and number of lifts. In 1959, the samples in each area except Black River were obtained from lifts of over 1,250,000 ft of gill net. Effort declined in all areas in each succeeding year. In 1962 only the Keweenaw Bay sample was based on more than 1 million ft of net; for Grand Marais, Whitefish Point, and Whitefish Bay the total was 200,000–315,000, and in all other areas except Black River, 625,000–981,000 ft. Effort in the Black River area declined from 253,000 ft in 1959 to only 42,000 ft in 1962. Although fishing effort was too low to yield reliable averages for this area in both 1961 and 1962, the CPE values for fin-clipped fish were very close to those from nearby Wisconsin waters near the Michigan border. CPE values from Black River for 1961–62 are included because they were entirely consistent with other data, but are, obviously, less reliable than those from other areas.

EARLIER MIGRATION STUDIES IN THE UPPER GREAT LAKES

The earliest large-scale, systematic study of lake trout movements in the upper Great Lakes was that of Smith and Van Oosten (1940), who tagged 1416 fish near Port Washington, Wisconsin, in Lake Michigan. These fish were 6–17 inches (152–432 mm) total length at tagging and averaged 12.8 inches

(325 mm). Of their 218 recaptures, 53% came within 1 year and 73% were within 25 miles (40 km) of the tagging site. It required 3 years for lake trout to become scattered throughout the lake. Most immature fish moved northward from the tagging site on the west-central shore and followed the shoreline. Mature fish were recaptured in all directions from the point of release. Four of the 218 fish had moved more than 125 miles (201 km).

Fry (1953) reported that nearly all tagged lake trout released in South Bay, Manitoulin Island (Lake Huron), remained within the bay. South Bay is connected to Lake Huron only through a shallow, 700-ft-wide (213-m) narrows.

Eschmeyer *et al.* (1953) reported on returns from 733 tagged native lake trout released in Lake Superior. Although only 25 mature fish were recaptured, the data suggested that large, mature fish tagged on spawning grounds near Keweenaw Point, Michigan, dispersed widely throughout the lake after the spawning season, but that most fish returned to the general vicinity of tagging in subsequent spawning seasons. Immature fish released just west of the Apostle Islands in Wisconsin were recovered (140 returns) in Wisconsin (76.4%), Minnesota (14.3%), and Michigan (9.3%). Although three fish had traveled at least 255 miles (410 km), 90% of the recoveries were within 50 miles (80 km) of the tagging locality.

Eschmeyer (1955) reported on 83 recaptures of mature lake trout tagged on spawning grounds near Marquette, Michigan. Of 33 fish returned in the 10-month intervals between spawning seasons, 25 were taken at distances of 14–198 miles (23–319 km) — average, 67 miles (108 km) — from the tagging site and eight were taken within 5 miles (8 km) of the tagging site. Five of these eight fish were taken within 1 month of the onset of the spawning season and might have been early arrivals on the grounds. Of 36 fish recaptured during subsequent spawning seasons, 27 were taken near the grounds where they were tagged, eight were taken near other spawning areas, and one was taken far from any known spawning ground. The remainder of the fish were recaptured within 26 days of tagging; 10 fish were on the grounds where tagged and four were on other spawning grounds 26–97 miles (42–156 km) from the tagging site. Because not all fish were actually spawning when tagged, some may have been en route to other spawning areas. The precise degree of "homing" could not, therefore, be determined.

Loftus (1958) reported that mature lake trout from river-spawning populations in eastern Lake Superior did not range widely. Most (96%) of the recoveries were within 30 miles (48 km) of the tagging site and only one fish was recaptured more than 70 miles (113 km) away. All stream recoveries were in the same streams where the fish were tagged, but nearby streams were not sampled until later years, after the stocks had been nearly exterminated.

TABLE IV. Number of lake trout from various plants caught per million ft (304,801 m) of commercial gill net lifted (CPE) in south and east sampling areas in each year of capture (dashes indicate no data).

Planting area, year(s), and age	Year captured	Area of capture								
		West of Keweenaw Peninsula			East of Keweenaw Peninsula					
		Apostle Islands	Black River	West Entry	Keweenaw Bay	Marquette	Munising	Grand Marais	Whitefish Point	Whitefish Bay
Apostle Islands										
1954 (yearlings)	1959	160.5	169.9	49.7	8.1	2.2	14.0	26.8	...	...
	1960	47.0	54.1	5.6	10.1	0.0	8.4	23.8	...	...
	1961	0.0	0.0	0.7	14.3	2.7	8.1	10.8	5.4	0.0
	1962	0.0	0.0	1.4	2.2	0.0	0.0	0.0	0.0	0.0
1956 (yearlings)	1959	258.5	118.5	128.3	4.6	1.3	8.2	15.4	...	...
	1960	570.9	576.6	269.3	26.8	1.1	22.2	59.5	...	...
	1961	683.0	954.4	254.0	94.2	29.9	78.7	68.6	27.2	2.8
	1962	660.1	856.8	130.4	88.3	68.7	107.1	79.6	27.4	9.5
1958 (yearlings)	1959	26.7	4.0	0.0	0.1	0.0	0.4	0.0	...	...
	1960	38.0	63.1	4.2	0.9	4.4	1.1	4.0	...	...
	1961	267.6	151.5	120.8	7.5	2.7	8.1	3.6	0.0	0.0
	1962	812.2	357.0	148.0	40.0	44.7	117.9	84.6	23.5	3.2
1959 (yearlings)	1959	3.1	0.0	0.0	0.0	0.0	0.0	0.0	...	...
	1960	9.8	0.0	1.3	0.0	0.0	0.0	0.0	...	...
	1961	40.8	45.5	10.2	2.9	0.0	0.0	1.8	0.0	0.0
	1962	805.0	71.4	146.7	9.8	12.8	24.1	14.9	0.0	0.0
1960 (yearlings)	1960	1.6	0.0	0.0	0.0	0.0	0.0	0.0	...	...
	1961	64.2	45.5	0.7	0.0	0.0	0.0	0.0	0.0	0.0
	1962	381.6	95.2	19.0	1.5	0.0	2.4	0.0	0.0	0.0
Keweenaw Bay										
1959 (2-year-olds)	1959	0.0	0.0	0.0	1.1	0.0	0.0	0.0	...	...
	1960	0.0	0.0	0.0	19.2	0.0	1.1	0.0	...	...
	1961	0.0	0.0	0.0	87.1	0.0	0.0	0.0	0.0	0.0
	1962	0.9	0.0	9.5	241.7	9.6	12.0	14.9	0.0	0.0
	1963	...	...	4.0	241.7	19.9	8.3	0.0	0.0	0.0

Keweenaw Bay										
	1960	0.0	0.0	0.0	0.0	0.0	0.0	0.0	...	...
1960	1961	0.0	0.0	0.0	11.8	0.0	0.0	0.0	0.0	0.0
(yearlings)	1962	0.0	0.0	0.0	96.2	1.6	7.2	10.0	0.0	0.0
	1963	...	...	1.0	427.8	59.6	11.22	0.0	13.3	0.0
Marquette										
	1959	0.0	0.0	0.0	0.4	2.6	0.0	0.0	...	...
1958	1960	0.0	0.0	0.0	8.2	13.2	24.3	0.0	...	...
(yearlings)	1961	0.0	0.0	0.0	27.8	65.3	98.5	16.2	10.9	0.0
	1962	0.0	0.0	0.0	20.6	55.9	60.2	14.9	0.0	3.2
	1959	0.0	0.0	0.0	3.0	1.3	0.0	0.0	...	...
1959	1960	0.0	0.0	0.0	36.3	0.0	7.4	0.0	...	...
(2-year-olds)	1961	0.0	0.0	0.0	56.4	61.7	1.8	0.0	0.0	0.0
	1962	0.0	0.0	0.0	110.7	116.6	42.4	10.0	0.0	0.0
	1959	0.0	0.0	0.0	0.4	0.0	0.0	0.0	...	...
1959	1960	0.0	0.0	0.0	24.1	7.7	14.8	0.0	...	...
(3-year-olds)	1961	0.0	0.0	0.0	18.6	6.4	5.4	9.0	0.0	0.0
	1962	0.0	0.0	0.0	6.8	14.4	14.4	5.0	11.8	0.0
Munising										
	1960	0.0	0.0	0.0	0.0	0.0	0.0	0.0	...	...
1960	1961	0.0	0.0	0.0	0.0	0.0	6.3	16.3	0.0	0.0
(yearlings)	1962	0.0	0.0	0.0	7.1	24.0	337.7	44.8	0.0	0.0
	1963	...	...	0.0	38.3	520.3	1,785.5	593.5	8.9	0.0
Whitefish Bay										
	1961	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1961	1962	0.0	0.0	0.0	0.6	0.0	15.7	5.0	0.0	3.2
(yearlings)	1963[a]	...	...	0.0	5.4	16.3	69.3	599.5	315.6	2,002.1

[a]CPE at Mamainse, Ontario, was 146.1.

TABLE V. Number of lake trout from various planting sites caught per million of feet of commercial gill net lifted (CPE) in each sampling area for each year at large, expressed as a percentage of the sum of the CPE values for all areas for each year at large (dashes indicate no data).

Planting area, year(s), and age	Years[a] at large	Area of capture									Total number of returns
		West of Keweenaw Peninsula			East of Keweenaw Peninsula						
		Apostle Islands	Black River	West Entry	Keweenaw Bay	Marquette	Munising	Grand Marais	Whitefish Point	Whitefish Bay	
Apostle Islands											
	1	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12
1954	2	77.4	18.0	4.1	0.1	0.0	0.4	0.0	0.0	0.0	234
1956	3	49.8	39.5	5.8	1.3	1.3	0.5	1.8	0.0	0.0	677
1958–60	4	50.2	26.8	18.5	1.0	0.5	1.5	1.5	0.0	0.0	2,784
(yearlings)	5	43.2	29.5	13.3	2.2	1.4	4.3	4.5	1.4	0.2	3,098
	6	33.9	41.2	11.5	3.1	1.0	3.4	4.6	1.2	0.1	2,911
	7	31.6	39.0	5.0	5.5	1.7	5.4	9.9	1.4	0.5	1,491
	8	0.0	0.0	1.7	34.0	6.4	19.3	25.7	12.9	0.0	60
	9	0.0	0.0	38.9	61.1	0.0	0.0	0.0	0.0	0.0	8
Keweenaw Bay											
	1	0.0	0.0	0.0	100.0	0.0	0.0	0.0	...	...	8
1959	2	0.0	0.0	0.0	94.6	0.0	5.4	0.0	...	...	64
(2-year-olds)	3	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	244
	4	0.3	0.0	3.3	83.7	3.3	4.2	5.2	0.0	0.0	813
	5	...	...	1.5	88.2	7.3	3.0	0.0	0.0	0.0	555
	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
1960	2	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	33
(yearlings)	3	0.0	0.0	0.0	83.6	1.4	6.3	8.7	0.0	0.0	325
	4	...	...	0.2	69.7	9.7	18.3	0.0	2.1	0.0	1,053
Marquette											
	1	...	...	...	...	...	...	...	...	...	...
1958	2	0.0	0.0	0.0	13.3	86.7	0.0	0.0	...	...	9
(yearlings)	3	0.0	0.0	0.0	17.9	28.9	53.2	0.0	...	...	62
	4	0.0	0.0	0.0	12.7	29.9	45.0	7.4	5.0	0.0	270
	5	0.0	0.0	0.0	13.3	36.1	38.9	9.6	0.0	2.1	156

Marquette											
	1	0.0	0.0	0.0	69.8	30.2	0.0	0.0	...	...	25
1959	2	0.0	0.0	0.0	83.1	0.0	16.9	0.0	...	...	126
(2-year-olds)	3	0.0	0.0	0.0	47.0	51.5	1.5	0.0	0.0	0.0	228
	4	0.0	0.0	0.0	38.6	40.7	17.2	3.5	0.0	0.0	476
	1	0.0	0.0	0.0	100.0	0.0	0.0	0.0	...	...	3
1959	2	0.0	0.0	0.0	51.7	16.5	31.8	0.0	...	...	100
(3-year-olds)	3	0.0	0.0	0.0	47.2	16.3	13.7	22.8	0.0	0.0	70
	4	0.0	0.0	0.0	13.0	27.5	27.5	9.5	22.5	0.0	47
Munising											
	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	...	...	0
1960	2	0.0	0.0	0.0	0.0	0.0	28.0	72.0	0.0	0.0	16
(yearlings)	3	0.0	0.0	0.0	1.5	5.2	83.6	9.7	0.0	0.0	369
	4	...	...	0.0	1.3	17.7	60.6	20.1	0.3	0.0	1,754
Whitefish Bay											
	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
1961	2	0.0	0.0	0.0	2.4	0.0	64.1	20.4	0.0	13.1	17
(yearlings)	3[b]	...	...	0.0	0.2	0.5	2.2	19.0	10.0	63.5	2,396

[a]The first year at large includes only the period from planting (April–June) until December 31. Other years are full calendar years.
[b]Value at Mamainse, Ontario, was 4.6.

MOVEMENTS OF LAKE TROUT RECAPTURED IN EXPERIMENTAL GEAR

Immediate Dispersal of Lake Trout Planted from Shore

To determine the time required for shore-planted lake trout to find suitable habitat and begin feeding, the M/V *Siscowet* made a series of trawl tows just offshore while lake trout were being planted from the beach at Frog Bay, Wisconsin (Fig. 1). Yearling fish (22/lb; 49/kg), planted in the spring of 1961, were captured at 5 fath (9 m) about 40 min after planting, at 10 fath (18 m) in 2½ hr, and at 15 fath (27 m) in 3½ hr. The depth of 15 fath, about 1 mile (1.6 km) from shore, was considered suitable habitat because both native and previously planted lake trout were abundant there. The experiment was repeated in the spring of 1962 with similar results. Another experiment with older fish in the fall of 1962 revealed that fall-planted 20-month-old lake trout dispersed faster than did spring-planted yearlings. The larger fall-planted fish (8/lb; 18/kg) reached 10 fathoms in about 1 hr, 1½ hr sooner than the spring-planted fish.

Stomachs were examined from lake trout planted in the spring of 1961 at 6, 24, and 48 hr after planting. The first evidence of feeding was obtained 48 hr after planting.

Dispersal Through the First Three Years of Liberty

The records of hatchery-reared lake trout captured in trawls in 1961–62 (Table I) offer a general idea of dispersal after planting at shore. Most of the lake trout were found in waters less than 2 miles (3.2 km) from the nearest planting site during the first 2 months after planting. The number of fin-clipped lake trout captured per hour of trawling decreased from 19.6 at less than 2 miles to 1.6 at 8–10 miles (13–16 km) from the planting site. No fish was taken at distances greater than 10 miles (16 km) during the first 2 months. In 3–4 months after release, the planted lake trout were most abundant (49.4 fish per hour of trawling) at 2–4 miles (3.2–6.4 km), and one fish was taken at 17 miles (27 km). Between 5 and 14 months after planting, the abundance of planted fish generally increased at distances greater than 4 miles and decreased at distances less than 4 miles from the planting site. Despite the apparent relation between time out and distance traveled, the fish were most abundant at 2–4 miles up to 18 months after planting. Catches in experimental gill nets supported the findings from trawl catches. Fish planted at Bayfield in 1960 were still most abundant at 2–4 miles from the planting site after 3 years at large.

The general decline in catch per unit effort of trawls in all areas after 14 months was probably due to the increased size of the fish and the more general dispersal to outlying waters. As the fish grew larger they became less vulnerable to the trawl. Lake trout more than 15 inches (381 mm) long were rarely taken in experimental trawls. As the fish spread to outlying waters, they obviously became relatively less abundant in areas adjacent to the planting site.

Little correlation was apparent between the average size of the lake trout and the rate of dispersal from the planting site. Catches made in trawls and experimental gill nets in 1963 provided comparisons among the average lengths of hatchery-reared lake trout taken at various distances and lengths of time at large (Table II). The average length of lake trout captured less than 2 miles (3.2 km) from the planting site (8.1 inches; 206 mm) was the same as that for fish caught more than 10 miles (16 km) away. The average lengths of fish at large 2–3 years were also nearly the same regardless of the distance traveled.

Fishing by the *Siscowet* was less intensive in Michigan waters of Lake Superior than in the Apostle Islands region, but yielded similar results. Fish which had been planted in lower Keweenaw Bay (Fig. 1) were most abundant 2–4 miles (3.2–6.4 km) from the planting site up to 3 years after planting. The abundance of hatchery-reared lake trout decreased progressively with distance from the planting site.

MOVEMENTS OF PLANTED LAKE TROUT CAUGHT IN COMMERCIAL GEAR

The total returns, in various sampling areas, of marked fish planted in a single area are sufficient to show where fish move. Variations in fishing intensity and sampling and the rates of movement and survival determine how many fish actually are recovered in the different areas. A measure of relative abundance of marked fish that is comparable in all sampling areas is needed, therefore, to show what proportion of the fish leave the area in which they were planted. The only measure of relative abundance that is reasonably dependable for comparisons among all sampling areas is the number of marked fish caught per unit effort. After release, lake trout become progressively more vulnerable to the commercial fishing gear, but do not reach a size that makes them fully vulnerable (roughly 20 inches long; 508 mm) for several years. Variation in growth of lake trout is so great that some individuals may reach 20 inches in the 3rd year after planting, but others do not attain this length until the 6th or 7th year. Comparisons of CPE values among the sampling areas are, therefore, valid only for fish from a given planting that have been at liberty the same number of years.

If CPE values for all areas in which fish from a given planting were caught are summed for a particular year of collection, CPE in any area can be expressed as a percentage of this sum. The "area percentage" or "percentage CPE" values are estimates of the relative abundance in each area of the surviving fish from a plant in the year considered. These percentages are comparable for different years of collection. If, for example, fish from a plant made in the Apostle Islands yield a CPE of 10 in the Apostle Islands area and 0 in all other sampling areas during the first year at large, the percentage CPE value in the Apostle Islands is 100. The following year this group of fish might yield a CPE of 40 in the Apostle Islands, 10 in the Black River area, and 0 in all

other areas. The CPE values are not comparable to those of the previous year because of the effects of mortality and of increased vulnerability to the gear through growth, but the percentage CPE values of 80 in the Apostle Islands and 20 at Black River are comparable. During the 1st year, all fish were still in the Apostle Islands area, but in the 2nd year they were one-fourth as abundant at Black River as in the Apostle Islands. In this example, substantial movement from the Apostle Islands to the Black River area would be indicated.

The information on returns of fin-clipped lake trout is presented in three forms. The total numbers of returns in the various areas from plants made in given areas (Table III, Fig. 2–6) show the locations of all returns and the directions of movement. The annual CPE values by area for various plants (Table IV) show the differences in catch rates (CPE values are computed only for major south shore sampling areas). Percentage CPE values computed by the method described above show the relative abundance of fish planted in various locations in each area (Table V). The percentages were listed by years at large; those for plants in the Apostle Islands, where all fish stocked were yearlings, are averages for several plants.

Lake Trout Planted in the Apostle Islands

Lake trout planted in the Apostle Islands were caught in every area sampled in US waters and in Ontario waters at the east end of the lake (Table III, Fig. 2). The bulk of the returns (8210) came from the Apostle Islands, but substantial numbers were taken in Michigan waters to the east. Most of the movement appears to have been along the shoreline through the waters off Black River (340 returns) and West Entry (1366 returns) into areas east of the Keweenaw Peninsula. Keweenaw Bay had 1117 returns but Marquette had only 137. Returns from both Munising (416) and Grand Marais (186) were greater than those from Marquette. Eastward movement continued into waters north of Whitefish Point (19 returns), but only five fish from the Apostle Islands were caught in Whitefish Bay. Apparently, the fish turned northward from Whitefish Point and entered Ontario waters (14 returns in 1961; no data for other years) along the east shore. The 34 returns from Minnesota waters at the extreme western end of the lake indicate some dispersal westward. The small number of returns (three) from other Minnesota waters indicates only limited movement northeastward along the Minnesota shore. The small numbers of returns from Isle Royale (five), Stannard Rock (one), and Caribou Island (four) suggest little movement to these offshore waters.

Although the total numbers of returns give the distinct impression that most lake trout planted in the Apostle Islands remained in the area, the CPE values (Table IV) indicate a substantial amount of movement. The CPE in areas east of the Apostle Islands increased progressively from west to east after the fish were released. The CPE for some plants was as high off Black River as in the Apostle Islands by the 3rd year at large. The relation of abundance in the various areas to length of time the fish were in the lake is illus-

trated better by the percentage CPE values (Table V). During the 1st year at large, returns came only from the Apostle Islands (percentage CPE, 100). In the 2nd year at large some fish were caught off Black River (percentage CPE, 18.0) and off West Entry (percentage CPE, 4.1) and a very few were caught east of the Keweenaw Peninsula. By the 4th year, the percentage CPE in the Apostle Islands had declined to 50.2 and had increased to 18.5 at West Entry, but was still low or nil east of the Keweenaw Peninsula. In the 5th year, the fish reached Whitefish Point and Whitefish Bay in the eastern part of the lake and the percentage CPE increased substantially in the areas from Keweenaw Bay east through Grand Marais. The percentage CPE continued to decline in the Apostle Islands, increased at Black River, and began to decline at West Entry. By the 7th year at large, percentage CPE had decreased to 31.6 in the Apostle Islands, was higher at Black River than in the Islands, and was over 5.0 in three areas east of the Keweenaw Peninsula. In the 8th and 9th years all returns came from outside the Apostle Islands region, but the total number of returns was small.

Marquette consistently had a lower percentage CPE than Keweenaw Bay, Munising, and Grand Marais, and had a lower value than Whitefish Point in some years. Fish from the Apostle Islands appear to bypass Marquette to some extent — perhaps by moving across deep water from the tip of the Keweenaw Peninsula to Munising and Grand Marais. Whitefish Bay had a very low value in all years. Although no CPE data were available from Ontario waters in 1959–62, the catch of 14 fish at Mamainse in 1961, a year of near collapse of fishing in Ontario, suggests strongly that fish from the Apostle Islands pass by Whitefish Bay and move northward into Ontario waters.

Lake Trout Planted in Keweenaw Bay

The available data for Keweenaw Bay cover two plantings and include returns in 1963. A planting of 2-year-old fish was made in 1959, and yearlings were stocked in 1960. Most of the returns (3282) came from Keweenaw Bay (Table III, Fig. 3). Principal movement out of the area was eastward, but only Marquette (55 captures) and Munising (100 captures) had enough returns to show significant movement. West Entry had 13 returns and the Apostle Islands had one return, the only evidence of limited dispersal westward.

The abundance data (Tables IV and V) suggest that the yearling fish of the 1960 plant dispersed more widely than did the 2-year-old fish planted in 1959. Fish from the 1959 planting tended strongly to remain near the planting site. In 2 of the 5 years at large, the percentage CPE in Keweenaw Bay was 100 and in the 5th year it was still 88.2. No fish from this planting moved as far east as Whitefish Point and few moved as far as Grand Marais. Fish from this plant were taken at West Entry in both the 4th and 5th years of liberty, but the percentage CPE was low in both years.

Dispersal of the 1960 plant was more strongly eastward. Although the percentage CPE in Keweenaw Bay was 100 in the 2nd year at large, it declined

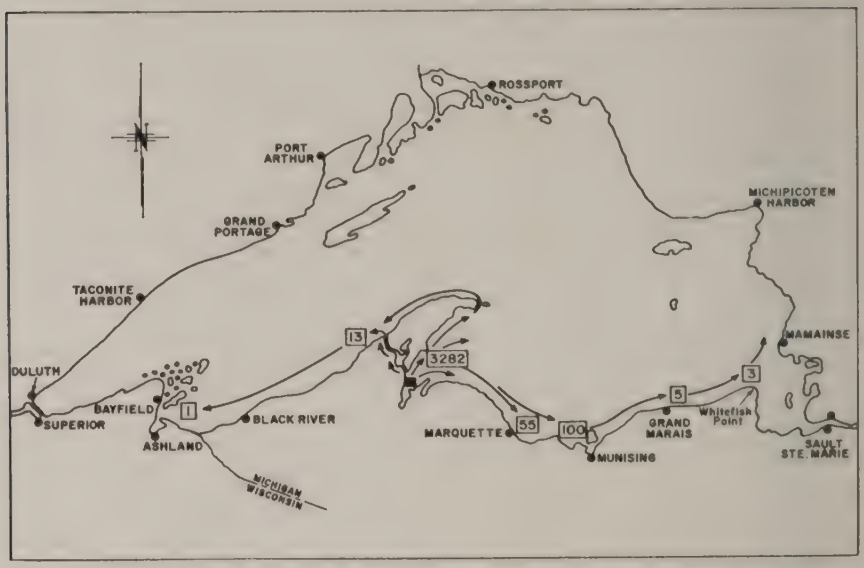

FIG. 3. Localities and number of returns of hatchery-reared lake trout planted in Keweenaw Bay. Black squares are planting localities and open rectangles give the number of fish caught in each area; arrows indicate direction of movement.

to 69.7 in the 4th year. A few fish from the plant reached Whitefish Point, but most of the movement was into waters near Marquette and Munising. Only one fish from the 1960 plant was taken at West Entry.

The fish that moved westward from Keweenaw Bay to West Entry and the Apostle Islands could have traveled either through the Keweenaw Waterway, a deep-water channel across the peninsula, or around the tip of the peninsula. The Keweenaw Bay entrance to the waterway lies within 7–8 miles (11.3–12.9 km) of the planting sites, and the waterway is only about 25 miles (40 km) long. The fact that no fish from these plantings were caught at West Entry until the 4th year at large suggests that some may have taken the longer route around the peninsula.

LAKE TROUT PLANTED OFF MARQUETTE

Yearling lake trout were planted off Marquette in 1958 and plantings of 2- and 3-year-old fish were made in 1959 (Tables III–V; Fig. 4). The older fish, as in Keweenaw Bay, dispersed differently from the yearlings. The total returns from all plants off Marquette suggest a strong westward movement into Keweenaw Bay (990 returns in the Bay and 292 off Marquette), but the abundance data show that the total returns are to a degree misleading.

Returns from the 1958 planting during the 2nd year at large (1959) indicated a significant movement into Keweenaw Bay (percentage CPE, 13.3) but most of the returns came from Marquette (percentage CPE, 86.7). Per-

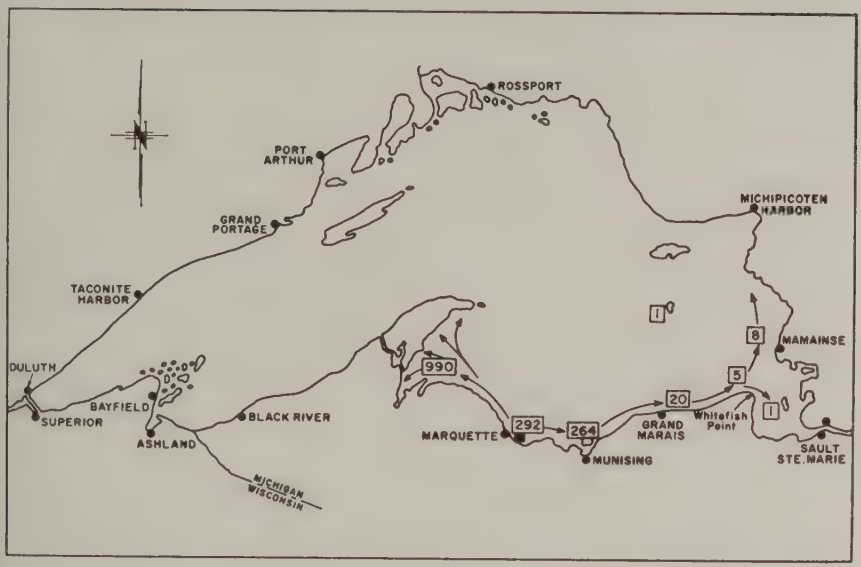

FIG. 4. Localities and number of returns of hatchery-reared lake trout planted off Marquette, Michigan. Black squares are planting localities and open rectangles give the number of fish caught in each area; arrows indicate direction of movement.

centage CPE increased little in the Bay after the 2nd year, but it declined at Marquette and increased progressively east of the planting site. Most of the movement from this plant was eastward.

Fish from the two 1959 plants were caught principally in Keweenaw Bay during the 1st year at large (percentage CPE values were 69.8 and 100). During the 2nd year, most of the fish planted as 2-year-olds were still caught in Keweenaw Bay (percentage CPE rose from 69.8 to 83.1) but the figure for those planted as 3-year-olds declined to 51.7. After the 2nd year, the percentage CPE for both groups declined in Keweenaw Bay and increased progressively from Marquette to Whitefish Point.

The early increase and later decline of the percentage CPE in Keweenaw Bay for the groups planted in 1959 suggest that most of the westward movement from Marquette to the Bay took place in 1959 and that most of the movement after 1959 was eastward. The almost constant percentage CPE in Keweenaw Bay for the 1958 fish suggests that much of the westward movement of this plant also took place in 1959. Some unusual condition seems to have existed in 1959; predominantly eastward movement could be expected for fish planted at Marquette in most years.

Only one fish from any of these plants was caught in Whitefish Bay, but five were taken north of Whitefish Point and eight were caught in Ontario in 1961 (data available for that year only). Fish from Marquette as well as those from the Apostle Islands appear to bypass Whitefish Bay. Only one

fish from these plants was taken in offshore waters and none was caught west of the Keweenaw Peninsula.

Lake Trout Planted off Munising

Yearling lake trout were planted at Munising in 1960 (Tables III V; Fig. 5). Fish from this planting were caught in all areas from Keweenaw Bay to Whitefish Point, but most of the returns were from Marquette to Grand Marais. Movements show little trend other than a random dispersal both eastward and westward along the shore. In the 3rd year at large, the percentage CPE was still 83.6 at Munising. In the 4th year, the percentage CPE declined to 60.6 at Munising and rose to 17.7 at Marquette and 20.1 at Grand Marais. No fish from this planting was caught in Whitefish Bay, offshore waters, or waters west of the Keweenaw Peninsula.

Lake Trout Planted in Whitefish Bay

A plant of yearling lake trout was made at the north end of Whitefish Bay only 1 mile (1.6 km) from the tip of Whitefish Point in 1961 (Fig. 6). Although the fish had been out only 3 years, the number of returns and CPE were large in 1963 (Tables III and IV). Data on both the number of returns and fishing effort were available from the Mamainse area in Ontario for 1963 and additional returns from unspecified gear were reported from both inshore

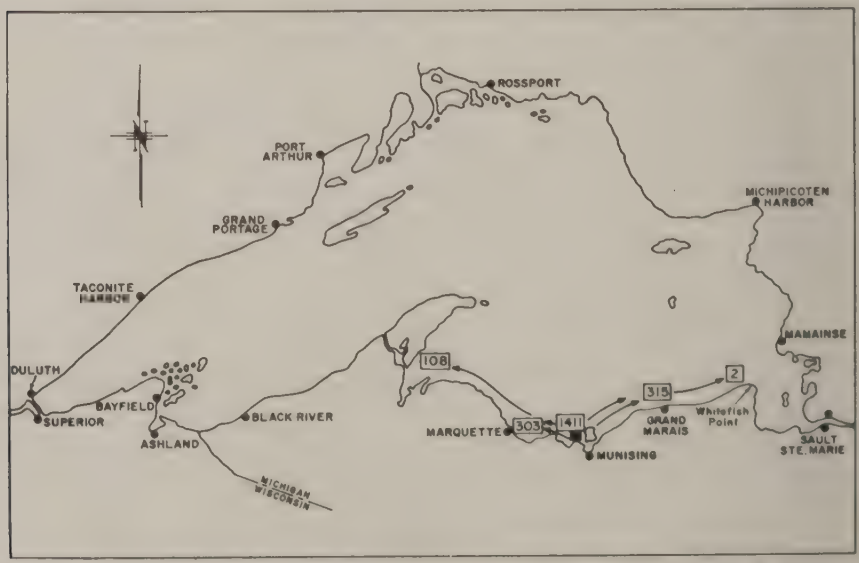

FIG. 5. Localities and number of returns of hatchery-reared lake trout planted off Munising. Black squares are planting localities and open rectangles give the number of fish caught in each area; arrows indicate direction of movement.

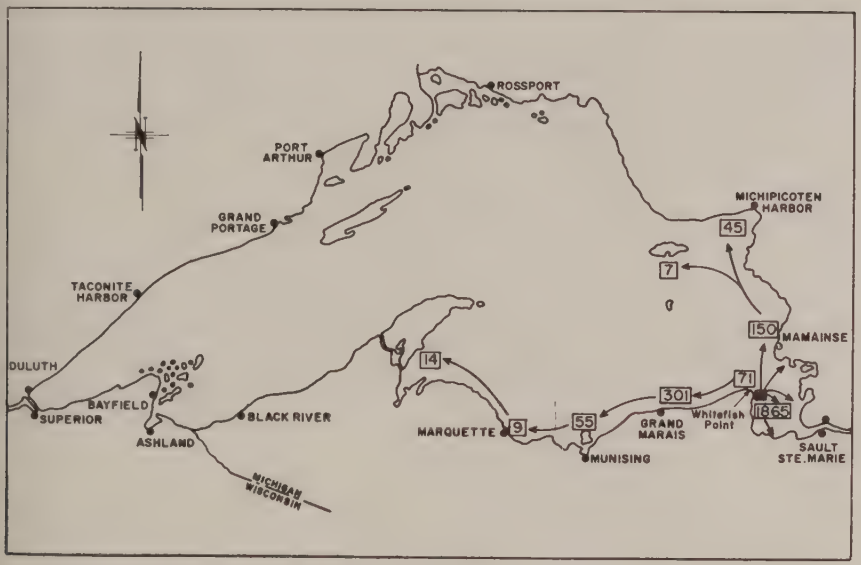

FIG. 6. Localities and number of returns of hatchery-reared lake trout planted in Whitefish Bay. Black squares are planting localities and open rectangles give the number of fish caught in each area; arrows indicate direction of movement.

and offshore waters (Michipicoten Harbor and Michipicoten Island), north of the Mamainse area for that year. The greatest number of fish was taken in Whitefish Bay, but many had moved into other areas. Returns came from every inshore area east of the Keweenaw Peninsula, and from all areas sampled in eastern waters of Ontario.

During the 3rd year at large, the percentage CPE was 63.5 in Whitefish Bay, 19.0 at Grand Marais, 10.0 north of Whitefish Point, and 4.6 in the Mamainse, Ontario, area (Table V). The relatively low percentage CPE off Whitefish Point as compared to Grand Marais is probably the result of sampling procedure. Samples were obtained from Whitefish Point only in the spring, but in both spring and fall at Grand Marais. The CPE values (Table IV) show that the vulnerability of these fish was increasing rapidly. Areas fished in the fall, therefore, had much higher CPE values than areas fished the previous spring. In the spring of 1963, the CPE was higher at Whitefish Point than at Grand Marais.

Although abundance of fish from this plant was highest by far in Whitefish Bay, many moved into the area north of Whitefish Point or into Ontario waters and dispersed westward or northward from there. The greatest movement was westward, but the percentage CPE was low west of Grand Marais. Movement northward to the Mamainse area was not great in view of its close proximity to the planting site. Although the Ontario returns from north of

the Mamainse area came from unspecified gear (which included some experimental trawls and small-mesh gill nets in addition to large-mesh commercial gill nets), the seven returns from the area south of Michipicoten Island indicate a greater offshore movement than from any single planting made in US waters. No fish from this planting was caught west of the Keweenaw Peninsula.

LAKE TROUT PLANTED IN CANADIAN WATERS

Although roughly $\frac{1}{2}$ million yearling lake trout have been planted in Ontario waters annually since the spring of 1958, returns of these fish in US waters have been few. The total number of returns of Canadian fish in all samples was 40 as compared to roughly 30,000 (including some fish not part of the materials of this report) for fish planted in US waters. Although Isle Royale lies within 20 miles (32 km) of the site of one of the Canadian plantings, only one Canadian fish has been taken there. Canadian hatchery-reared lake trout have obviously made no important contribution to the populations in US waters.

THE RELATION BETWEEN SURFACE CURRENTS AND MOVEMENTS OF LAKE TROUT

Unless influenced by some strong external force, lake trout would be expected to disperse gradually in all possible directions from a planting site. Movements of planted lake trout in Lake Superior obviously have not been random. Fish stocked in the Apostle Islands region moved almost exclusively eastward to Michigan and Ontario waters, but the only movement from plantings east of the Keweenaw Peninsula to areas west of the peninsula was from plantings in Keweenaw Bay, and the number that moved was small. Fish planted in Keweenaw Bay tended strongly to remain in the area, and those that left the Bay generally moved eastward. Lake trout planted off Marquette moved generally eastward except in 1959. Fish planted in all areas outside Whitefish Bay bypassed that bay almost completely. A factor in this diversion may have been the shallow area that extends northward into the lake proper just to the west of Whitefish Point. Movement to offshore areas was low or nil from all plants. Only fish planted at Munising and in northern Whitefish Bay moved roughly at random along the shore. A comparison of movements of planted lake trout and of surface currents of Lake Superior suggests that currents are a principal factor influencing movements.

Lake trout usually are found at depths less than 50 fath (91 m) — most fishing is done at 10–45 fath (18–82 m) — and the 50-fath contour is less than 10 miles (16 km) from shore over most of southern Lake Superior. Hence, concentrations of lake trout are limited by depth to the areas along the shoreline.

The surface currents[3] (Fig. 7) in Lake Superior are generally counterclockwise and are much stronger along the south shore than along the north

[3]Although current studies in Lake Superior have all been done with floating bottles or cards, fishermen along the south shore have indicated that the currents extend to depths of about 45 fath during periods of high winds.

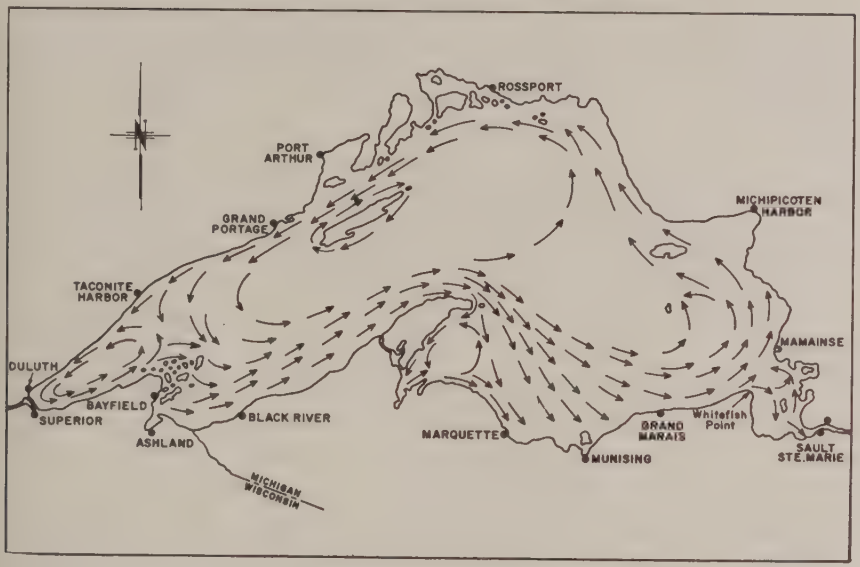

FIG. 7. Surface currents of Lake Superior.

shore. Large eddies exist in the extreme western end of the lake and in Keweenaw Bay. Whitefish Bay has only a weak counterclockwise flow. The currents are generated primarily by the prevailing westerly winds and are occasionally broken up by heavy winds from the east or northeast.

Similarities between the current flow and movements of lake trout (compare Fig. 2–4 with Fig. 7) indicate that lake trout move with the currents. If currents are responsible for the movements, areas with eddies or weak currents should show limited and random movement of lake trout. Lake trout planted in Keweenaw Bay tended to remain in the area. No fish have been planted in the eddy at the western end of the lake, but Eschmeyer *et al.* (1953) released tagged native lake trout on the Wisconsin shore in this area. About 90% of their recoveries were in Wisconsin waters or Minnesota waters west or northwest of the release point. Only one fish was caught in Minnesota northeast of the area covered by the eddy. Only 9.3% of the recoveries were in Michigan waters and these fish showed movements similar to those of hatchery-reared fish planted in the Apostle Islands. Although the data of Eschmeyer *et al.* (1953) are not strictly comparable to those from hatchery-reared fish, they indicate that lake trout within the eddy at the west end of the lake tend to remain there and that those that do move follow the current.

The evidence that currents exert a major influence on lake trout movements is summarized as follows:

1. Most of the movement of fish from the Apostle Islands followed the strong south-shore current eastward. Although a few fish moved westward into

the eddy at the west end of the lake, very few hatchery-reared or native fish moved up the Minnesota shore against the current.

2. Movement of fish from regions of eddies was far less than in areas of strong currents.

3. Movement to areas west of the Keweenaw Peninsula was insignificant from plants made in Keweenaw Bay and nil from other plantings farther east. (It is possible that fish stocked in the south end of Keweenaw Bay reached waters to the west through the Keweenaw Waterway and that none rounded Keweenaw Point.)

4. Movement from Keweenaw Bay and Marquette was mainly eastward with the current except in 1959.

5. The greatest amount of movement to an offshore area (from Whitefish Bay to Michipicoten Island) followed the main current.

6. Movement of lake trout from the bays and islands of the Ontario north shore to US waters has been insignificant. Currents are weak in this region. Movement from Ontario waters of extreme eastern Lake Superior against the current to US waters has also been negligible.

The lack of any strong trend in movements of fish planted at Munising and the predominantly westward movement of fish from the 1961 plant that moved out of northern Whitefish Bay are exceptions to the general statements on the effects of surface currents on lake trout movements. Currents in the eastern part of Lake Superior may be too weak, too variable, or too far offshore to have much influence on movements of fish planted in these areas. Recoveries of drift bottles released east of Grand Marais and north of Whitefish Point have shown that the eastward flowing current within about 4 miles (6.4 km) of shore is indeed weak. The stronger current 4–10 miles (6.4–16.1 km) offshore north of Whitefish Point moves northeastward into Ontario waters. More detailed knowledge of currents than is presently available is necessary for better understanding the relation with movements of lake trout in the eastern part of the lake. Although fish from all plantings show some tendency to disperse at random from a planting site, the relation between surface currents and major movements of lake trout seems to be strong.

SUMMARY OF MOVEMENTS OF LAKE TROUT

The proportion of planted lake trout that moves out of the general area of a planting site depends on the locality where the fish are planted and increases with the length of time the fish are at large. Dispersal from a planting site begins immediately after the fish are planted and probably continues until the fish are mature. Evidence that mature native lake trout disperse widely but return to the same grounds to spawn each year suggests that movements of mature fish may be entirely different from those of immature ones.

Fish from all plants in their dispersal from the planting site appeared not to go deeper than about 50 fath (91 m) offshore. Lake currents exerted an influence on dispersal and, in general, movement of lake trout was with the current. Fish planted in areas of strong currents dispersed more rapidly than those planted in regions of weak currents or eddies.

Whether lake trout are planted from boats within a few miles of shore or from shore should have little effect on the rate of dispersal to other areas. Lake trout planted from shore reach habitat occupied by both native and boat-planted fish within a few hours after planting.

Neither shore- nor boat-planting in inshore waters is effective for stocking offshore areas.

Where hatchery-reared lake trout will spawn remains to be determined. If lake trout should exhibit a true "homing" behavior and return to planting sites to spawn, present planting practices may have to be altered.

ACKNOWLEDGMENTS

Several people helped obtain materials for this study. A.H. Lawrie, Fisheries Research Board of Canada, Biological Station, London, Ontario, provided data requested on 1961 and 1963 returns of fin-clipped lake trout in eastern Ontario waters. C.R. Burrows, Minnesota Department of Conservation, St. Paul, Minnesota, provided 1963 data for Minnesota waters. Several commercial fishermen on Keweenaw Bay and at Marquette, Michigan, voluntarily provided information on their catches of lake trout in 1959 and 1960. Alfred M. Beeton, Bureau of Commercial Fisheries, Ann Arbor, Michigan, provided unpublished material on surface currents and advised in the preparation of Fig. 7. Ralph Hile read the manuscript and offered suggestions for presentation of the material.

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Reprinted from TRANSACTIONS OF THE AMERICAN FISHERIES SOCIETY
Vol. 94, No. 1, January 1965
pp. 75–83

Age, Growth, Maturity, and Fecundity of "Humper" Lake Trout, Isle Royale, Lake Superior

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ABSTRACT

Humper lake trout are one of the several races or subpopulations of lake trout in Lake Superior. This study is based on 3,705 fish collected on a reef south of Isle Royale near the eastern end. The mean lengths of humper trout from commercial gill nets were smaller than those of lean lake trout. Members of age-groups VII, VIII, and IX represented 81.5 per cent of the commercial humper catch. The body–scale relation was described by two intersecting straight lines. The weight of humper trout increased as the 3.282 power of the length. Growth in length was slow and ranged from 1.6 to 3.5 inches per year. Annual increments were greatest in the first, sixth, and seventh years. Growth in weight was also slow but increased each year. Humper trout became legal (1½ pounds) in the eighth year of life and reached 5 pounds in 11 years. All fish longer than 19.1 inches and older than age-group VIII were mature; the shortest mature fish were: males, 12.7 inches; females, 14.7 inches. At minimum legal size, 98 per cent of the males and 56 per cent of the females were mature. Humper trout produced an average of 1,351 eggs per fish or 516 per pound.

INTRODUCTION

Although several forms of lake trout exist in Lake Superior, only two, the "lean trout" (*Salvelinus namaycush namaycush*) and the siscowet (*Salvelinus namaycush siscowet*), have been given subspecific status. The humper trout is one of the forms of lake trout recognized by Lake Superior commercial fishermen. Eschmeyer (1957) designated all these various forms, including such groups as humpers and the stream-spawning stocks described by Loftus (1958), as races or subpopulations and reported the probable existence of as many as a dozen in Lake Superior.

Humper lake trout are also known among commercial fishermen as "humpies," "bankers," or "paperbellies." Humpers are deep-bodied fish which have a thin abdominal wall and a short head with a convex snout. They typically have a bronze-green back and more brightly colored fins than do lean trout. They resemble the siscowet in external appearance but the thin ventral body wall and the limited amount of fat on the viscera distinguish them from the siscowet. Eschmeyer and Phillips (1965) determined that the regression of percentage fat of the flesh on length for humper trout differs from those of both the siscowet and lean trout. The fat content of humpers is generally greater than that of lean trout but less than that of siscowets. For any given length, humper trout weigh less than siscowets but are heavier than lean trout.

Humpers live on isolated offshore reefs surrounded by water deeper than 50 fathoms, such as those near Isle Royale and Caribou Island. Their spawning season begins in mid-September. The August-spawning lake trout of Superior Shoal in northeastern Lake Superior (Ontario) appears to be similar to humpers in United States waters.

Humpers comprised an insignificant part of the United States production of lake trout until the late 1950's. Commercial landings of lake trout declined from 4,699,000 pounds in 1950 to 367,000 pounds in 1961, primarily as the result of depredations by the sea lamprey (*Petromyzon marinus*)—see Baldwin (1963) for a recent review of the sea lamprey problem. As fishing success for lean lake trout and siscowets declined, some fishermen turned to fishing less desirable races. Humpers usually bring lower prices than lean trout due to their relatively higher fat content. Accurate catch statistics for different kinds of lake trout are not available because they are all reported as lake trout. Data supplied by two of the principal producers of humpers in U. S. waters indicate, however, that the proportion of these fish in the catch had increased to roughly 5 per cent in 1959 and nearly 9 per cent in 1961. Production was about 45,000 pounds in 1959 but only 28,000 pounds in

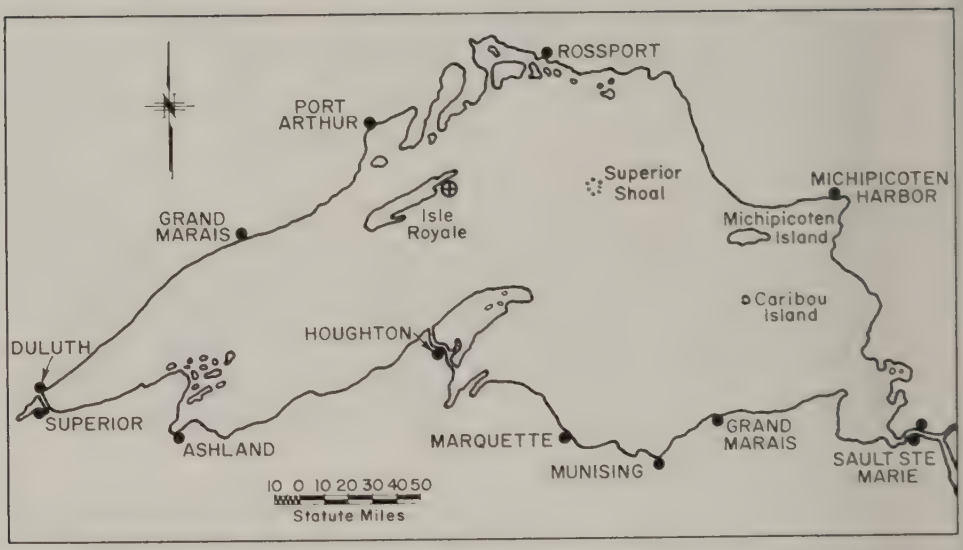

FIGURE 1. Lake Superior. The circle with cross indicates sampling area off Isle Royale.

1961. Catches of humpers are probably of considerable importance at the present time to Canadian fishermen who include humpers in a general category they call "bankers" or "bank trout."

This report is the first dealing with the life history of humper lake trout.

MATERIALS AND METHODS

The present study is based on 3,705 humper trout taken from a large reef 4–5 miles off the southerly shore of Isle Royale, abreast of Rock Harbor (Figure 1). The fish were captured in July, August, and September 1959 and July and August 1963 (Table 1). Most of the humpers were caught by a commercial fisherman in 4½-inch-mesh nylon gill nets fished on the bottom in 20–45 fathoms. The remainder were collected in experimental gill nets (1- to 4-inch mesh) fished by the Bureau of Commercial Fisheries research vessel *Siscowet*. Scale samples were taken from 258 fish in 1959 and 315 in 1963.

The total length of each fish (tip of head to tip of tail, lobes compressed) was determined to the nearest 0.1 inch. Weights of 268 fish were read, either to the nearest 0.1 pound or to the nearest 0.1 ounce, on spring balances. All weights given in this paper are in pounds.

Sex and state of maturity were recorded for 472 fish. A fish was considered mature if it would have spawned in the fall of the year of capture.

All scale samples were taken from the area between the base of the dorsal fin and the lateral line. Scale impressions were made in cellulose-acetate strips (Smith, 1954) and magnified 83 diameters by a microprojector. Diameters of scales and growth fields were measured to the nearest millimeter along a line passing through the focus and roughly bisecting the anterior field. Lengths at each

TABLE 1.—*Collections of humper lake trout off Isle Royale, 1959 and 1963*

Year and month	Kind of gill net			
	Commercial		Experimental	
	Total number	Scale samples	Total number	Scale samples
1959				
July	596	80	—	—
August	793	84	80	80
September	943	14	—	—
1963				
July	321	156	—	—
August	895	82	77	77
Total	3,548	416	157	157

annulus were determined from a nomograph constructed from data on the body–scale relation.

Age groups were designated by Roman numerals corresponding to the number of annuli. All fish were considered to have passed into the next higher age group on 1 January. Fish collected between 1 January and the time of annulus formation were credited with an annulus at the edge of the scale. The majority of the scales did not exhibit new growth at the time of collection. No great difficulty was encountered in the determination of age from humper trout scales.

Egg counts were made for 25 humper trout.

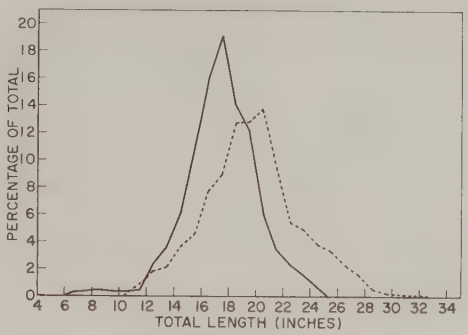

FIGURE 2.—Length distribution of humper lake trout (solid line) and lean lake trout (broken line), caught in 1959 and 1963.

LENGTH DISTRIBUTION OF THE COMMERCIAL CATCH

The length composition of the commercial catch of humper lake trout differed considerably from that of lean lake trout taken in the vicinity of Marquette, Michigan, even though all fish were caught by nets of the same mesh size (Table 2, Figure 2). Humper trout (average length 17.4 inches) were much shorter than lean trout (19.7 inches). Fish in the length interval of 15.0–19.9 inches made up 72.1 per cent of the humper trout catch and only 46.6 per cent of the lean trout. Fish 20.0 inches and longer comprised only 14.0 per cent of the humper but 45.0 per cent of the lean trout. The modes of the length distribution were at 17.0–17.9 inches for humpers and 20.0–20.9 inches for lean trout.

TABLE 2.—*Length distributions of humper lake trout taken near Isle Royale and lean lake trout captured off Marquette, Michigan, 1959 and 1963*

[All fish taken in 4½-inch-mesh gill nets]

Total length (inches)	Humper trout		Lean trout[1]	
	Number	Percentage	Number	Percentage
6.0– 6.9	7	0.2	—	—
7.0– 7.9	11	0.3	—	—
8.0– 8.9	14	0.4	—	—
9.0– 9.9	10	0.3	—	—
10.0–10.9	11	0.3	2	0.1
11.0–11.9	15	0.4	16	0.8
12.0–12.9	80	2.3	39	1.8
13.0–13.9	128	3.6	45	2.1
14.0–14.9	218	6.1	76	3.6
15.0–15.9	387	10.9	96	4.5
16.0–16.9	566	16.0	164	7.7
17.0–17.9	676	19.1	189	8.9
18.0–18.9	497	14.0	269	12.7
19.0–19.9	429	12.1	273	12.8
20.0–20.9	220	6.2	290	13.7
21.0–21.9	121	3.4	198	9.3
22.0–22.9	83	2.3	114	5.4
23.0–23.9	54	1.5	102	4.8
24.0–24.9	21	0.6	81	3.8
25.0–25.9	—	—	70	3.3
26.0–26.9	—	—	48	2.3
27.0–27.9	—	—	33	1.6
28.0–28.9	—	—	11	0.5
29.0–29.9	—	—	5	0.2
30.0–30.9	—	—	2	0.1
31.0–31.9	—	—	1	<0.1
32.0–32.9	—	—	1	<0.1
Total number	3,548	100.0	2,125	100.0
Average length	17.4	—	19.7	—

[1] Total catch of lean trout from Marquette, Michigan, in July, August, and September 1959 and July and August 1963.

LENGTH DISTRIBUTION OF THE AGE GROUPS

The length distributions of the 573 humper lake trout for which ages were determined (Table 3) indicate small ranges in length for individual age groups and limited overlap between adjacent age groups. The greatest span between the longest and shortest fish in an age group was 6 inches (VIII group), but most age groups had a span of 4 or 5 inches. Only two of the length intervals (13.0–13.9 and 17.0–17.9 inches) contained fish of more than two ages. Length, therefore, appears to be a reasonably good index to the age of humper trout from Isle Royale.

No fish were legal size in age-groups II–VI. The percentage legal was 20.0 per cent in the VII group and 98.2 per cent in the VIII group; all older fish were legal size.

AGE COMPOSITION OF THE COMMERCIAL CATCH

The age composition of the commercial catch of humper lake trout (3,548 fish) was estimated by applying the percentage age

TABLE 3.—*Length distribution of the age groups of humper lake trout from Isle Royale, 1959 and 1963*

Total length (inches)	Age group									
	II	III	IV	V	VI	VII	VIII	IX	X	XI
4.0– 4.9	1	—	—	—	—	—	—	—	—	—
5.0– 5.9	—	—	—	—	—	—	—	—	—	—
6.0– 6.9	—	7	—	—	—	—	—	—	—	—
7.0– 7.9	—	6	7	—	—	—	—	—	—	—
8.0– 8.9	—	—	17	—	—	—	—	—	—	—
9.0– 9.9	—	—	10	5	—	—	—	—	—	—
10.0–10.9	—	—	2	13	—	—	—	—	—	—
11.0–11.9	—	—	—	25	3	—	—	—	—	—
12.0–12.9	—	—	—	14	12	—	—	—	—	—
13.0–13.9	—	—	—	2	51	2	—	—	—	—
14.0–14.9	—	—	—	—	32	6	—	—	—	—
15.0–15.9	—	—	—	—	—	67	2	—	—	—
16.0–16.9	—	—	—	—	—	53	8	—	—	—
17.0–17.9	—	—	—	—	—	1	59	1	—	—
18.0–18.9	—	—	—	—	—	—	28	13	—	—
19.0–19.9	—	—	—	—	—	—	11	37	—	—
20.0–20.9	—	—	—	—	—	—	2	31	—	—
21.0–21.9	—	—	—	—	—	—	—	11	6	—
22.0–22.9	—	—	—	—	—	—	—	—	20	4
23.0–23.9	—	—	—	—	—	—	—	—	—	1
24.0–24.9	—	—	—	—	—	—	—	—	—	3
Total number	1	13	36	59	98	129	110	93	26	8
Average length	4.9	6.9	8.7	11.3	13.7	15.8	17.8	19.8	22.1	23.2
Percentage legal[1]	0.0	0.0	0.0	0.0	0.0	20.0	98.2	100.0	100.0	100.0

[1] Legal size is 1½ pounds, round weight. The total length which corresponds to this weight is 16.5 inches.

composition of each length interval of Table 3 to the total number of measured fish in that interval. The commercial fishery for humper trout depended primarily on fish from the age-groups VII, VIII, and IX which represented 81.5 per cent of the total catch, and 91.6 per cent of all legal fish (Table 4). Fish of age-groups III–VI contributed about 12.0 per cent of the total catch, but all were less than the legal weight of 1½ pounds (see also Table 3).

The lack of fish in age-groups I and II, and the small numbers of fish in age-groups III and IV were undoubtedly attributable to gear selectivity. The relatively small numbers of fish in the older age groups (X and XI) suggest high total mortality in the later years. The nets fished on the reef were capable of taking these older, larger fish in good numbers had they been present.

TABLE 4.—*Age composition of humper lake trout from Isle Royale caught in 4½-inch-mesh commercial gill nets, 1959 and 1963*

Age group	Total catch		Legal fish[1]	
	Number	Percentage	Number	Percentage
III	12	0.3	—	—
IV	28	0.8	—	—
V	74	2.1	—	—
VI	341	9.6	—	—
VII	918	25.9	258	10.8
VIII	1,189	33.5	1,156	48.1
IX	785	22.1	785	32.7
X	112	3.2	112	4.7
XI	89	2.5	89	3.7
Total	3,548	100.0	2,400	100.0

[1] Legal size is 1½ pounds, round weight. The total length which corresponds to this weight is 16.5 inches.

LENGTH–WEIGHT RELATION

The length–weight relation of humper lake trout (Table 5) was based on all available fish combined regardless of year, month of capture, sex, and state of maturity. The length–weight relation surely varies during the year and differs for ripe and spent females, but insufficient data (only 268 fish) were available to study these variations.

The length–weight curve of Figure 3 represents the calculated weights computed from the equation:

$$W = 1.5332 \times 10^{-4}\ L^{3.28243},$$

where W = weight (pounds),

and L = total length (inches).

The equation was obtained by fitting a straight line by least squares to the logarithms of the average lengths and weights within the

TABLE 5.—*Length–weight relation of humper lake trout from Isle Royale, 1959 and 1963*

Number of fish	Total length (inches)[1]	Weight (pounds)	
		Empirical	Calculated
1	4.9	0.04	0.03
1	7.1	0.1	0.1
1	7.5	0.1	0.1
4	8.7	0.2	0.2
1	10.3	0.3	0.3
5	10.6	0.4	0.4
5	11.2	0.4	0.4
4	11.6	0.4	0.5
6	12.2	0.5	0.6
7	12.7	0.6	0.6
9	13.1	0.6	0.7
12	13.7	0.8	0.8
8	14.3	0.9	0.9
18	14.7	1.1	1.1
21	15.2	1.2	1.2
13	15.7	1.3	1.3
21	16.2	1.5	1.4
22	16.7	1.6	1.6
18	17.2	1.8	1.7
22	17.7	2.0	1.9
7	18.2	2.2	2.1
15	18.7	2.4	2.3
9	19.1	2.6	2.5
12	19.6	2.8	2.7
14	20.2	3.2	3.0
6	20.7	3.4	3.2
4	21.7	4.0	3.8
2	22.6	4.5	4.3

[1] Means for fish within 0.5-inch length intervals.

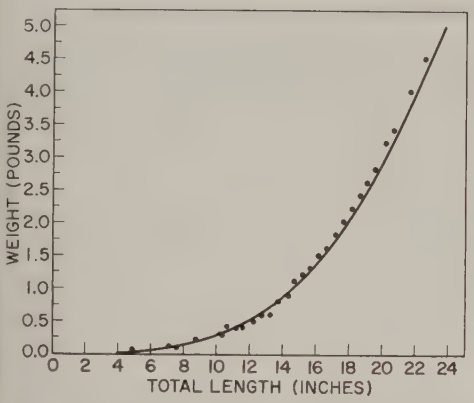

FIGURE 3.—Length–weight relation of humper lake trout from Isle Royale, 1959 and 1963. The curve represents the calculated weights and the dots the empirical weights.

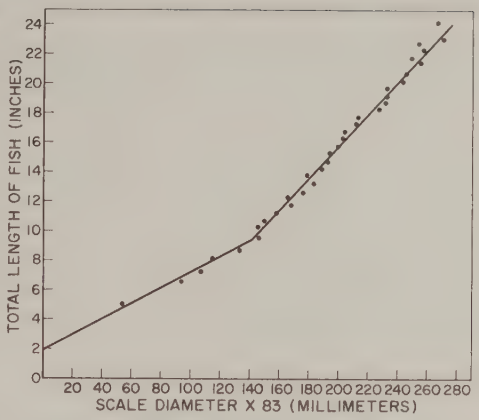

FIGURE 4.—Relation between total length and magnified scale diameter (× 83) of humper lake trout from Isle Royale, 1959 and 1963.

different length intervals. The value of n (above 3) indicates that humpers become progressively "plumper" with increase in length.

The empirical and calculated weights generally agreed closely. The greatest discrepancies were at 20.0–22.6 inches, where the difference was 0.2 pound. The total length corresponding to the minimum legal weight of 1½ pounds is 16.5 inches.

BODY–SCALE RELATION

The body–scale relation of humper lake trout was determined from the average diameter of five scales from each of 573 fish (Table 6, Figure 4). The graph of mean scale diameters and mean total body lengths for 0.5-inch intervals of length indicated the relation could be described adequately by two straight lines intersecting at a length of about 9.5 inches. The straight lines fitted by least squares to the means of scale diameters and lengths of fish had these equations:

$$L = 0.0524S + 1.93 \quad (L < 9.5 \text{ inches}),$$
$$\text{and } L = 0.110S - 6.22 \quad (L > 9.4 \text{ inches}),$$

where S = scale diameter (83×) in millimeters, and L = total length in inches. The lower segment of the body–scale line had an intercept of 1.9 inches on the length axis. No known factor in the life history appears to be associated with the change of slope at 9.5 inches.

Calculations of length were made with a nomograph based on the fitted lines of Figure 4.

Description of the body–scale relation of humper lake trout by two straight lines lacks an attractive rational basis but tests of more elaborate treatments proved unproductive. Logarithmic plots of the relation, $L = cS^n$ (c and n constant), were not linear. Neither did the relation $L - a = cS^n$ give linear plots at a values of 1, 2, 3, and 4 inches.

TABLE 6.—*Relation between fish length and the diameter of the scales of humper lake trout from Isle Royale, 1959 and 1963*

Number of fish	Total length[1] (inches)	Scale diameter (millimeters × 83)	Number of fish	Total length[1] (inches)	Scale diameter (millimeters × 83)
1	4.9	54	36	15.7	199
7	6.6	94	28	16.2	203
13	7.3	107	33	16.7	204
6	8.1	115	28	17.2	212
11	8.7	133	33	17.7	213
15	9.5	146	23	18.2	227
6	10.2	146	18	18.7	231
9	10.6	150	30	19.1	232
16	11.2	158	18	19.6	233
12	11.7	168	19	20.2	243
10	12.2	166	14	20.7	245
16	12.6	176	8	21.4	255
22	13.2	183	9	21.7	249
33	13.7	179	17	22.2	258
15	14.2	188	7	22.7	254
23	14.7	192	1	23.0	270
33	15.2	194	3	24.1	267

[1] Means for fish within 0.5-inch length intervals.

TABLE 7.—*Calculated total lengths (inches) of humper lake trout from Isle Royale, 1959 and 1963*

Age group	Number of fish	Length at end of year of life										
		1	2	3	4	5	6	7	8	9	10	11
II	1	2.9	4.5	—	—	—	—	—	—	—	—	—
III	13	3.3	4.8	6.4	—	—	—	—	—	—	—	—
IV	36	3.4	5.2	7.0	8.5	—	—	—	—	—	—	—
V	59	3.5	5.3	7.2	8.8	11.3	—	—	—	—	—	—
VI	98	3.5	5.3	7.1	8.7	10.9	13.6	—	—	—	—	—
VII	129	3.5	5.2	7.0	8.6	10.8	13.2	15.7	—	—	—	—
VIII	110	3.5	5.1	6.8	8.5	10.7	13.4	15.6	17.8	—	—	—
IX	93	3.4	5.0	6.6	8.2	10.1	12.8	15.3	17.5	19.7	—	—
X	26	3.4	4.8	6.6	8.3	10.1	12.8	15.2	17.6	19.8	22.1	—
XI	8	3.2	4.8	6.3	7.8	9.2	11.5	14.2	16.7	18.9	21.0	23.2
Grand average calculated length		3.5	5.1	6.9	8.5	10.7	13.2	15.5	17.6	19.7	21.8	23.2
Increment of average		3.5	1.6	1.8	1.6	2.2	2.5	2.3	2.1	2.1	2.1	1.4
Grand average increment of length		3.5	1.6	1.8	1.6	1.9	2.6	2.4	2.2	2.2	2.3	2.2
Sum of average increment		3.5	5.1	6.9	8.5	10.4	13.0	15.4	17.6	19.8	22.1	24.3

CALCULATED GROWTH IN LENGTH

The average calculated lengths of male and female humper lake trout exhibited no differences; the sexes were combined, therefore, for the preparation of Table 7.

The calculated lengths exhibited a detectable trend to be higher for fish of younger age groups of Isle Royale humper trout than for the older age groups. The agreement was generally good over the first 3 years of life but in years 5–7 the calculated lengths decreased fairly consistently with increase in the age of the fish on which they were based. Agreement was reasonably good again beyond the seventh year except for the slowly growing XI group. Decrease of calculated lengths with increase in age has been attributed to several different causes by various authors. If the population is exploited by a commercial fishery, the discrepancies are usually held to originate in gear selectivity and the progressive destruction of the faster growing fish in a year class as it passes through the fishery. Discrepancies among calculated lengths have been reported also, however, in some unexploited fish populations. It is not possible in this study to give a positive explanation of the phenomenon; the fairly intensive commercial fishery in this area may, however, be the major factor.

The estimates of the general growth in length at the bottom of Table 7 are based on the grand average calculated lengths and on the successive summation of the grand average increments of length. The lengths computed by the two methods were identical in 5 years and differed by only 0.1 to 0.3 inch in 5 others. The largest difference was 1.1 inches at the end of the eleventh year of life. The sums of the grand average increments were used to prepare Figure 5, since they avoid the irregularities caused by successive dropping out of age groups.

Growth in length of humper lake trout varied within narrow limits beyond the first year (Figure 5). The annual increment of length was highest, 3.5 inches, in the first year. Thereafter the increments ranged from 1.6 to 1.9 inches in the fourth through the sixth years and from 2.2 to 2.6 inches in the sixth through the eleventh. Humper trout reached a length of 1 foot in the sixth year of life, 1½ feet in the ninth, and 2 feet in the eleventh.

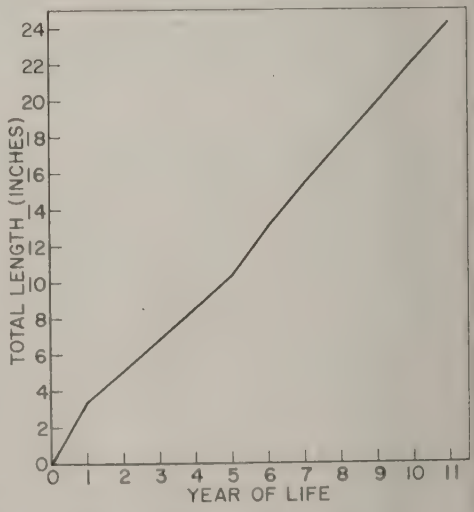

FIGURE 5.—Calculated length of humper lake trout from Isle Royale, 1959 and 1963.

TABLE 8.—*Growth of lake trout in different parts of the Great Lakes*

[Calculated lengths at end of indicated year of life for humper lake trout and for Lake Michigan lake trout reported by Cable and by Van Oosten and Eschmeyer; data from Loftus based on lengths at capture of spawning-run fish and read from Figure 4, page 266, of his paper; growth as given by Eschmeyer for the south shore of Lake Superior are lengths at capture at end of completed growing season; Fry's data are mean lengths at capture during summer following indicated year of life. Fork lengths given by Loftus and by Fry converted to total lengths by formula: Total length = 1.082 fork length + 0.045 inch. Fish studied by Cable were principally recoveries from plantings of hatchery-reared fingerlings]

Area and author	Total length (inches)										
	1	2	3	4	5	6	7	8	9	10	11
Lake Superior											
"Humpers" (present report)	3.5	5.1	6.9	8.5	10.4	13.0	15.4	17.6	19.8	22.1	24.3
Montreal River											
Loftus (1958)	—	—	—	—	—	24.9	28.0	31.0	32.3	33.0	33.4
Dog River											
Loftus (1958)	—	—	—	—	—	20.0	25.2	26.0	26.6	28.4	29.3
South Shore											
Eschmeyer (1956)	3.9	6.7	8.6	—	—	—	—	—	—	—	—
Lake Michigan											
Northern											
Cable (1956)	6.9	10.0	12.8	16.1	19.0	21.8	24.2	26.4	28.7	—	—
Southern											
Cable (1956)	5.6	8.8	12.1	15.3	18.4	21.0	23.2	25.0	—	—	—
All areas											
Van Oosten and Eschmeyer (1956)	3.4	7.1	10.1	12.1	14.0	16.8	18.6	20.0	25.0	27.0	—
Lake Huron											
Fry (1953)	—	10.9	13.8	17.9	20.4	22.9	24.6	—	—	—	—

[1] From South Bay, Manitoulin Island.

Humper trout were shorter at any given age than the lake trout taken from other areas in the Great Lakes (Table 8). The only exception was at the first annulus where humper trout were 0.1 inch longer than the Lake Michigan trout studied by Van Oosten and Eschmeyer (1956). Differences of length at an age of 7 years provide a good comparison of growth. Humper trout, at the seventh annulus, were 9.8 and 12.6 inches shorter than the two river-spawning stocks reported by Loftus (1958) from eastern Lake Superior.

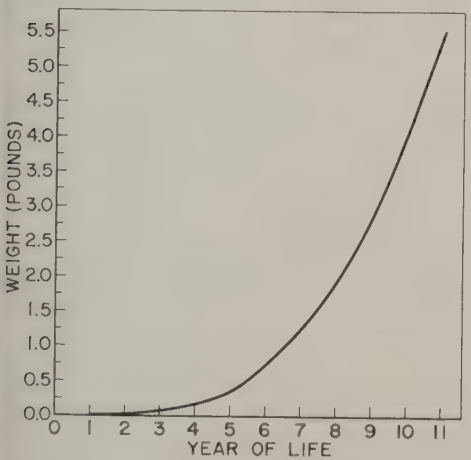

FIGURE 6.—Calculated growth in weight of humper lake trout from Isle Royale, 1959 and 1963.

At the seventh annulus, Lake Michigan lake trout reported by Van Oosten and Eschmeyer (1956) were 3.2 inches longer than humper trout. Those studied by Cable (1956) were 7.8 and 8.8 inches longer in the southern and northern areas of Lake Michigan, respectively. Lake Huron lake trout (Fry, 1953) were 9.2 inches longer than humper trout at the seventh annulus.

CALCULATED GROWTH IN WEIGHT

The calculated weights of Table 9 were computed by applying the calculated lengths (sum of the average increments) of Table 7 to the length–weight equation. The annual increments of weight of humper lake trout increased in every year of life. Growth in weight (Figure 6) was slow the first 5 years

TABLE 9.—*Calculated weights (pounds) and annual increments of weight of humper lake trout from Isle Royale, 1959 and 1963*

Year of life	Calculated weight (pounds)	Increment (pounds)
1	0.01	0.01
2	0.03	0.02
3	0.09	0.06
4	0.17	0.08
5	0.33	0.16
6	0.70	0.37
7	1.21	0.51
8	1.88	0.67
9	2.77	0.89
10	3.97	1.20
11	5.42	1.45

TABLE 10.—*Sex ratio of humper lake trout from Isle Royale, 1959 and 1963*

Age group	Number of males	Number of females	Percentage males
III	5	1	83.3
IV	15	12	55.6
V	24	18	57.1
VI	38	29	56.7
VII	64	46	58.2
VIII	51	54	48.6
IX	34	54	38.6
X	7	15	31.8
XI	2	3	40.0
All ages	240	232	50.8

TABLE 11.—*Relation of length to maturity of humper lake trout from Isle Royale, 1959 and 1963*

Total length (inches)	Males			Females		
	Number immature	Number mature	Percentage mature	Number immature	Number mature	Percentage mature
12.0–12.9	9	1	10.0	10	—	0.0
13.0–13.9	14	13	48.2	9	—	0.0
14.0–14.9	2	10	83.3	11	3	21.4
15.0–15.9	8	25	75.8	7	12	63.2
16.0–16.9	—	29	100.0	10	14	58.3
17.0–17.9	1	32	97.0	4	20	83.3
18.0–18.9	—	14	100.0	6	15	71.4
19.0–19.9	—	21	100.0	1	26	96.3

(range, 0.01 to 0.16 pound per year) and then increased more rapidly (range, 0.37 to 1.45 pounds per year). Humper trout weighed only 0.33 pound at the end of the fifth year of life. They reached 1 pound in the seventh year and became legal (1½ pounds) in the eighth year. The weight was nearly 4 pounds in 10 years and over 5 pounds in 11.

SEX RATIO

Sex records were available for 472 humper lake trout, most of which were collected at least 1 month prior to spawning (Table 10). The number of males exceeded that of females in age-groups III–VII but the females were the more numerous in age-groups VIII–XI. Extremes ranged from 83.3 per cent males for age-group III (only 6 fish) to 31.8 per cent males for the X group (22 fish). Among age groups represented by more than 25 fish the range in the representation of males was 38.6 to 58.2 per cent. For all age groups combined, the percentage of males was 50.8 per cent.

SIZE AND AGE AT MATURITY

All humper lake trout shorter than 12.7 inches were immature, and all fish longer than 19.1 inches were mature (Table 11). The shortest mature male was 12.7 inches long. Nearly 50 per cent of the males were mature at 13.0–13.9 inches, and all (one exception at 17.1 inches) were mature at lengths greater than 15.9 inches.

The first mature females appeared at 14.0–14.9 inches (shortest mature individual, 14.7 inches) and 50 per cent maturity was exceeded at 15.0–15.9 inches. All females longer than 19.1 inches were mature. The smallest mature male was 2 inches shorter than the smallest mature female and males reached 100 per cent maturity at a length 2 inches shorter than did the females.

All humper trout younger than age-group VI were immature and all fish older than the VIII group were mature. The percentage of mature males was greater than that of mature females in age-groups VI, VII, and VIII (Table 12). The mature fish of each sex were

TABLE 12.—*Length of mature and immature fish and percentage maturity by age for humper lake trout from Isle Royale, 1959 and 1963*

[All fish younger than the VI group were immature and all older than the VIII group were mature]

Age group and item	Males			Females		
	Mature	Immature	Difference or percentage mature	Mature	Immature	Difference or percentage mature
VI						
Total length[1] (inches)	13.8	13.3	0.5	14.7	13.7	1.0
Number of fish	19	19	50.0	1	26	3.7
VII						
Total length[1] (inches)	15.1	15.1	0.0	16.0	15.7	0.3
Number of fish	59	1	98.3	22	17	56.4
VIII						
Total length[1] (inches)	17.6	17.1	0.5	18.0	18.0	0.0
Number of fish	46	1	97.9	42	11	79.2

[1] Calculated length at last annulus.

TABLE 13.—*Production of eggs by humper lake trout from Isle Royale, 1959 and 1963*

Total length (inches)		Average weight (pounds)	Number of fish	Number of eggs per fish		Number of eggs per pound of fish	
Interval	Average			Range	Average	Range	Average
15.0–15.9	15.6	1.3	4	411– 901	680	343–644	523
16.0–16.9	16.5	1.6	2	427–1,033	730	285–646	471
17.0–17.9	17.7	2.1	4	979–1,443	1,225	490–687	597
18.0–18.9	18.5	2.2	3	757–1,565	1,179	360–652	528
19.0–19.9	19.6	2.7	3	1,072–1,477	1,330	370–627	487
20.0–20.9	20.2	3.3	3	1,273–1,739	1,576	386–543	483
21.0–21.9	21.4	3.6	3	1,615–2,640	2,169	461–593	597
22.0–22.9	22.5	4.4	3	1,740–2,258	1,976	405–502	446

generally longer than immature fish of the same age.

Commercial catches of lean lake trout from Lake Superior are composed mostly of immature fish (Eschmeyer, 1955). Humper lake trout, on the other hand, do not attain legal size until their eighth year (Table 9). At this age approximately 98 per cent of the males and 56 per cent of the females were mature. The undersize males and females of age-group VI were approximately 50 and 4 per cent mature, respectively. This small size at maturity has an important survival value to humper lake trout. Much of the spawning stock is not available to the commercial fishery and the fish also have a good chance to spawn before they are attacked by the sea lamprey which preys most heavily on the larger individuals (the isolated habitat on offshore reefs also may offer some protection from lampreys). The stocks of humper trout are, therefore, in a good position to maintain their abundance.

FECUNDITY

Egg counts were made on ovaries from 25 mature females collected in August 1959 and 1963. The number of eggs in an ovary was determined by the Burrows displacement method as described by Leitritz (1959).

The number of eggs per individual ranged from 411 at lengths of 15.0–15.9 inches to 2,640 at 21.0–21.9 inches (Table 13). The average for the entire sample was 1,351 eggs per fish. The number of eggs increased irregularly with increase in length of the fish. The number per pound of fish averaged 516 and ranged from 285 to 687. The number per pound showed no trend with increasing fish weight.

Humper lake trout produced far fewer eggs than other Lake Superior lake trout. Eschmeyer (1955) gave the range in egg production of southern Lake Superior lean lake trout, 25.1 to 38.0 inches in total length, as 2,476 to 17,119 per fish. Siscowets ranging from 16.8 to 34.2 inches, total length, produced 1,093 to 10,476 eggs per fish. The number of eggs per pound of lean trout averaged 646, somewhat above the mean for humper trout.

The average diameter of humper lake trout eggs was 4.4 mm. Eschmeyer reported a similar diameter for eggs of lean lake trout.

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Made in United States of America
Reprinted from JOURNAL OF MAMMALOGY
Vol. 46, No. 3, 26 August 1965
pp. 504–505

OFFSHORE SOUTHWARD MIGRATION OF GRAY WHALES OFF SOUTHERN CALIFORNIA

The migration routes of the California, or eastern Pacific, population of the gray whale (*Eschrichtius gibbosus*) have been recorded in some detail by Gilmore (U. S. Fish and Wildlife Service, Spec. Sci. Rep.—Fish., 342: 30 p., 1960a; Norsk Hvalfangst–Tidende, 49: 409–431, 1960b) and Pike (J. Fish. Res. Board Canada, 19: 815–838, 1962). Many migrating gray whales closely follow the coastline, and it has been assumed that nearly all the southbound whales pass within sight (i.e., about 5 km) of the mainland of southern California. Gilmore (1960a) said that they had not been observed far off the coast of southern California, but a few sightings at Isla Guadalupe and Isla Clarion suggested that a few of them traveled offshore past the Channel Islands off southern California.

Between 7 and 28 January 1964 I conducted a whale-marking cruise aboard the whale catcher *Lynnann*, on charter to the Bureau of Commercial Fisheries from the Golden Gate Fishing Company of Richmond, California. This period coincided with the peak of the southward migration of the gray whale (Gilmore, 1960a; Rice, Norsk Hvalfangst–Tidende, 50: 219–225, 1961). We worked off the coast of southern California between 32° N and 38° N lat. Our marking program is directed primarily toward the commercially utilized species, especially fin whales (*Balaenoptera physalus*) and sperm whales (*Physeter catodon*). During the cruise, we sighted gray whales offshore on 15 occasions, involving 37

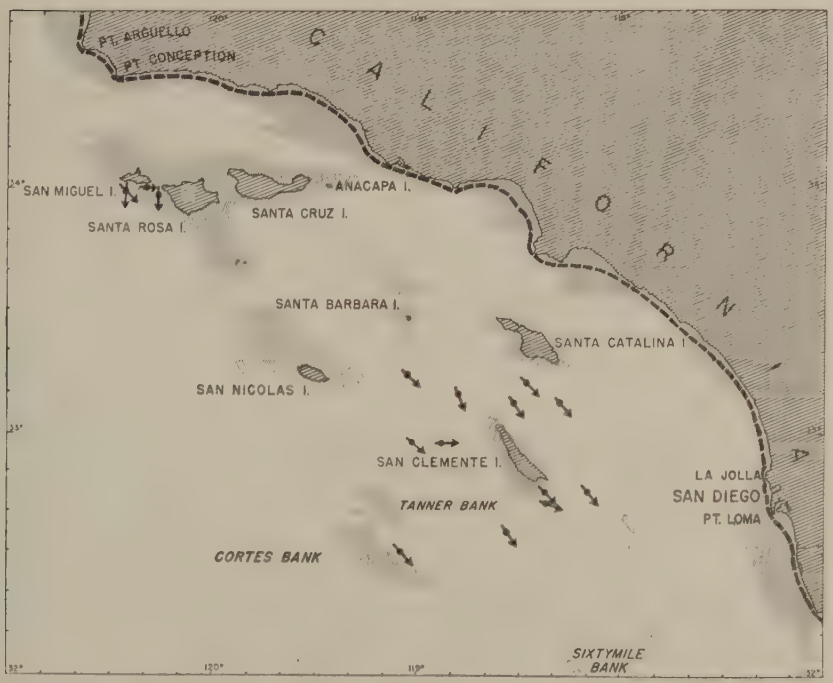

FIG. 1.—Waters off southern California. Dots with arrows show position and bearing of migrating pods of gray whales sighted offshore between 9 and 24 January 1964. The heavy dashed line indicates the major inshore migration route. Shaded areas indicate water depths less than 180 m (100 fm).

TABLE 1.—*Offshore sightings of gray whales off southern California, 9–24 January 1964*

Date	POSITION		Number of whales	Direction of travel
	N lat	W long		
9 Jan.	33°59′	120°25′	1, 1	S, SE
" "	33°57′	120°16′	2	S
" "	34°00′	120°19′	2	E
13 "	33°13′	118°27′	2	SE
" "	33°08′	118°31′	1	SE
" "	32°58′	118°52′	3	E
" "	32°58′	119°01′	1	SE
16 "	33°08′	118°17′	1	SE
" "	32°46′	118°22′	2	SE
" "	32°43′	118°21′	3	ESE
" "	32°31′	119°04′	5	SE
20 "	32°36′	118°33′	6	SE
23 "	32°46′	118°09′	2	SE
24 "	33°10′	118°47′	2	SSE
" "	33°15′	119°02′	3	SE

animals (Table 1). We made no effort to locate gray whales, but sighted most of them while we were en route to waters farther offshore. When the direction of movement of each pod is plotted on a chart (Fig. 1), it is apparent that a proportion of the southbound gray whales, after passing Point Arguello and Point Conception, leaves the mainland shore and fans out through the Channel Islands. All of the observed gray whales were well within the 1,800 m (1,000 fm) isobath, and were east of a line drawn along the western edge of the Channel Islands and associated banks: Point Arguello—San Miguel Island–San Nicolas Island–Cortes Bank. All the whales were bearing between east and south, with the majority heading generally southeast. If they continued in the same direction, they would strike the coast of northern Baja California, considerably south of San Diego, California.

Although these data are not quantitative, when they are compared with shore observations, it appears that an unknown but perhaps large proportion of the gray whales passes southern California far offshore, where they would be missed by the counts conducted at Point Loma (Gilmore, 1960a, b; Rice, 1961). The total population could thus be considerably larger than the published censuses indicate. The counts, however, may be a reliable index of relative population size. It is possible that varying (and unknown) oceanographic conditions in 1963–1964 caused a larger number of the gray whales than usual to migrate farther offshore. This season the vanguard of the migration arrived at La Jolla, California, at least a week later than usual, according to Raymond M. Gilmore. Another possibility, suggested by Dr. Gilmore, is that the increasing gray whale population has resulted in a larger proportion of the animals forsaking the inshore route; during the 1963–1964 season, there appears to have been more gray whales close inshore than during any previous season, although no systematic count was made. The possible effect on gray whale behavior of increasingly heavy small boat traffic in the inshore waters, the major whale migration path, also must be considered.

Kenneth C. Balcomb, Masaharu Nishiwaki, and Captain Loyd Newton and the crew of the *Lynnann* assisted in the field observations. Raymond M. Gilmore provided useful information and suggestions.—DALE W. RICE, *U. S. Fish and Wildlife Service, Bureau of Commerical Fisheries, Marine Mammal Biological Laboratory, Sand Point NAS, Bldg. 192, Seattle, Washington 98115.* *Accepted 10 January 1965.*

Reprinted from Norsk Hvalfangst-Tidende 1965, No. 5, p. 114—115

Bryde's Whale in the Gulf of Mexico

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Bryde's Whale in the Gulf of Mexico

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On 5 April 1965 a Seattle newspaper published an ssociated Press wirephoto of a 38-foot (11.6 m) hale of the genus *Balaenoptera* which stranded ive near Panacea, on the Gulf Coast of Florida pproximately 30°02' N, 84°22' W) on 2 April 1965. wo days later the Coast Guard towed the animal sea, and it reportedly swam away. The photo-aph (Figure 1) clearly shows on the dorsal sur-ce of the snout the pair of lateral longitudinal dges diagnostic of Bryde's whale, *B. edeni* (Omu-, 1962). I sent the photograph to Dr. Hideo Omura the Whales Research Institute, Tokyo, who con-rred in the identification (*in litt.* 14 April 1965).

Bryde's whale has been reported from many wide-scattered parts of the world in waters warmer an 20° C (Omura, 1959). On zoogeographical rounds, it would be expected to occur in the north-estern Atlantic and the Gulf of Mexico. The near-t localities from which it has previously been re-rted are Curaçao (Soot-Ryen, 1961) and Grenada Anonymous, 1927) in the West Indies. In the east-ern North Atlantic it has been reported from Benzu, Spanish Morocco (Committee for Whaling Statistics, 1950), and near Dakar, Sénégal (Cadenat, 1957).

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Figure 1. — Thirty-eight foot Bryde's whale *Balaenoptera edeni* stranded at Panacea, Florida; note the prominent lateral ridge on each side of the median ridge on the snout. Wid World Photos.

TRANSACTIONS

OF THE

SAN DIEGO SOCIETY OF NATURAL HISTORY

VOLUME 14, No. 7, pp. 73-84

PINNIPED POPULATIONS AT ISLAS GUADALUPE, SAN BENITO, AND CEDROS, BAJA CALIFORNIA, IN 1965

BY

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SAN DIEGO, CALIFORNIA

PRINTED FOR THE SOCIETY

DECEMBER 28, 1965

Fig. 1. Isla Guadalupe, Baja California, showing the census areas listed in table 2, the location of elephant seal rookeries and hauling grounds, and the area occupied by fur seals.

Fig. 2. Isla Cedros, Baja California, showing the census areas listed in table 2.

PINNIPED POPULATIONS AT ISLAS GUADALUPE, SAN BENITO, AND CEDROS, BAJA CALIFORNIA, IN 1965

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Between January 28 and February 3, 1965, we made censuses of the northern elephant seals, *Mirounga angustirostris*, Guadalupe fur seals, *Arctocephalus philippii townsendi*, and California sea lions, *Zalophus californianus californianus*, inhabiting Isla Guadalupe, the Islas San Benito, and Isla Cedros, Baja California, Mexico. This project was a cooperative effort of the Mexican Instituto Nacional de Investigaciones Biológico Pesqueras (INIBP) and the U. S. Fish and Wildlife Service (FWS). The censuses were made during whale-marking cruises of the whale catcher boats *Lynnann* and *Sioux City*, under charter from the Golden Gate Fishing Company of Richmond, California.

These three species of pinnipeds are of particular interest to biologists and conservationists. The elephant seal, nearly extinct before the turn of the century, has experienced a rapid population growth. The population may now be leveling off on Guadalupe, where regulated exploitation is being considered. Over 90 percent of the northern elephant seal population breeds on Isla Guadalupe and the Islas San Benito. The Guadalupe fur seal was heavily exploited during the last century, and until 11 years ago was feared extinct. The population apparently has only recently entered a phase of rapid growth. The fur seal is known to breed only on Isla Guadalupe. The California sea lion is abundant and unexploited (except for a small number taken in the Gulf of California). There has been agitation, especially in California, for reduction of its numbers because of alleged damage to fisheries. The feasibility of rational exploitation of sea lions is now being considered. Islas San Benito and Isla Cedros harbor some of the largest rookeries and hauling grounds of this species.

Our censuses are particularly useful for determining population changes, because they were made at exactly the same time of year as censuses made 15 years previously by Bartholomew and Hubbs (1952). The number of pinnipeds hauled out on any rookery or hauling ground may change markedly throughout the year, depending on migrations and phases of the breeding cycle. Daily variations must also be considered.

ACKNOWLEDGMENTS

We wish to acknowledge the indispensable help of the crew members of the vessels: Captain Loyd Newton, Ernesto Gonzales, and Robert Young of the *Lynnann;* and Captain Donald Gamble, Gordon Holmes, and Julio Ninayahuar of the *Sioux City*. Joaquin Arvizu M. of the INIBP and Kenneth Balcomb III of the FWS assisted in making the counts. Lt. Pablo Vásquez V., commanding officer of the naval garrison on Isla Guadalupe, and his men offered valuable assistance. Carl L. Hubbs supplied much valuable information concerning pinnipeds on these islands, and made many useful criticisms of the manuscript. George A. Bartholomew supplied information on elephant seals in the Channel Islands, and reviewed the manuscript. Richard A. Jennings provided the elephant seal count for Año Nuevo Island. Victor B. Scheffer and Ford Wilke reviewed the manuscript.

METHODS

We made our counts in three ways, depending upon terrain and sea conditions: (1) by walking the beaches; (2) by following the shoreline in outboard-powered skiffs; or (3) by cruising as closely as possible along shore with the *Lynnann* and *Sioux City*, which are 41 m. (135 ft.) long and draw about 3 m. (10 ft.).

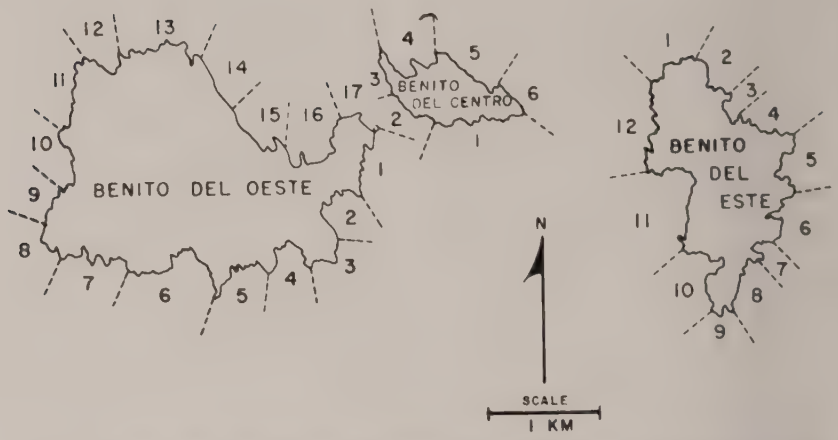

Fig. 3. Islas San Benito, Baja California, showing the census areas listed in table 2; these areas are the same as those used by Bartholomew and Hubbs (1952).

When it was impossible to count every individual in large compact masses of sea lions and elephant seals, we counted sample sectors containing 10 to 100 animals, and estimated the total number by visually dividing the total occupied area into sectors equivalent to the counted sample areas.

Isla Guadalupe, January 28-31. — We covered on foot all portions of the east shore inhabited by fur seals, except for certain small areas (see below) that were too precipitous; in such areas we used a small boat. We also covered on foot the largest elephant seal rookeries — those at Pilot Rock Beach and the Barracks Beaches. The sector between these two rookeries was observed from a small boat. We followed the remainder of the east shore and all of the west shore in the *Lynnann*, about 0.5 to 1 km. offshore. We circled Islote Zapato in a small boat. Islote Toro, which we observed from the *Lynnann*, apparently is not used by pinnipeds, as it has no suitable hauling-out areas.

Islas San Benito, February 2-3. — We walked almost entirely around Benito del Oeste, except for a short sector at the west end of the south shore that was impassable. The latter we observed from a skiff. The surf prevented us from landing on Benito del Centro and Benito del Este, but we circumnavigated them in a small boat less than 0.25 km. off shore.

Isla Cedros, February 3. — The entire east shore and the southern half of the west shore were followed with the vessels *Lynnann* and *Sioux City*, respectively. The northern half of the west shore was observed from a small boat.

RESULTS

The counts are summarized in table 1; details for each island appear in table 2 and figures 1 to 3. Because Bartholomew and Hubbs (1952, 1960) and Hubbs (1956) reviewed the history of the pinniped populations on these islands and cited the earlier literature, we have alluded only briefly to past censuses.

Elephant Seals. — January is the height of the breeding season of the northern elephant seal (Bartholomew, 1952). At the time of our observations nearly all the pups had probably been born, and the number of breeding adults was probably near maximum. When censusing large groups of elephant seals, we found it impossible to count all the pups, because many were concealed by the much larger adults. We made complete counts of living pups at two

TABLE 1

Summary of 1965 pinniped censuses on Isla Guadalupe (Jan. 27-31), Islas San Benito (Feb. 2-3) and Isla Cedros (Feb. 3).

Island	*Mirounga*			*Arctocephalus*	*Zalophus*
	1 year old and older	Pups	Total		
Isla Guadalupe	6,721	3,668[1]	10,389	285	585
Islas San Benito					
Benito del Oeste	967	376	1,343		2,596
Benito del Centro	448	174[1]	622		2,236
Benito del Este	645	250[1]	895		2,326
San Benito subtotal	2,060	800	2,860		7,158
Isla Cedros	47		47	3	8,407
Grand total	8,828	4,468	13,296	288	16,150

[1]Calculated number; see text.

rookeries and found the ratio of adults to pups. At the North Barracks Beach rookery at Isla Guadalupe, the ratio was 1 : 0.57. At the other large rookeries on Isla Guadalupe we counted only the animals older than pups, and estimated the number of pups by assuming that the ratio was the same as found at the North Barracks Beach rookery. If hauling grounds as well as rookeries are included, the ratio of older animals to pups on Guadalupe is estimated at 1 : 0.55. Along the entire shoreline of Isla Benito del Oeste, the ratio of older animals (including those on hauling grounds as well as those on rookeries) to pups was 1 : 0.39. Among the many groups of elephant seals on Benito del Centro and Benito del Este, we did not distinguish between rookeries and hauling grounds; to estimate the number of pups, we applied the Benito del Oeste proportion.

In the early 19th century, according to Scammon (1874), elephant seals occupied many rookeries and hauling grounds along the coast and on offshore islands, from Point Reyes, California (38°00′ N) south to Cabo San Lazaro, Baja California (24°48′ N). Subsequently, they were nearly exterminated, and by 1892, as far as is known, only 20 to 100 animals remained, all on Isla Guadalupe. In the following 68 years they increased to an estimated 15,000 (Bartholomew and Hubbs, 1960) and recolonized parts of their former range (see below).

In January and February, 1950, Bartholomew and Hubbs (1952) counted 4,548 elephant seals on Guadalupe. This count included only animals one year old and older (Bartholomew, *in litt.*). In January, 1960, Bartholomew and Hubbs (1960) counted 9,000 elephant seals on the east shore of Guadalupe, and estimated 11,000 on the entire island, including pups. We counted 6,721 seals older than one year, and estimated 3,668 pups, for a total of 10,389. These counts suggest that the Guadalupe population reached a peak by 1960, and has stopped growing.

One factor tending to limit further population growth may be increased mortality of pups because of crushing by the adults (see Bartholomew, 1952:392) on the crowded rookeries (fig. 4). Although we did not count the dead pups, there were many on the upper edges of the beaches (fig. 5) above the breeding aggregations, where some of the moribund pups crawl. Many other dead pups could be seen when the tightly packed adults moved about. Some were almost completely buried in the sand. Several dead pups were seen floating in the water off the rookeries. These observations indicate that only a small percentage of the pup carcasses was visible. Studies should be made to determine the extent and causes of pup mortality in relation to population density on the rookeries.

Fig. 4. Female elephant seals on the rookery at North Barracks Beach, Isla Guadalupe. Such dense crowding results in many pups being crushed to death, as the one in the lower left. January 28, 1965. (KWK 65-2-15)

Elephant seals re-established themselves on the Islas San Benito by 1918; in 1950, Bartholomew and Hubbs (1952) counted 908, excluding pups. Our count of 2,060, excluding pups, suggests that the San Benito population is still increasing at about the same rate as the Guadalupe population did during its phase of rapid growth (Bartholomew and Hubbs, 1960).

The elephant seals apparently have only recently recolonized Isla Cedros. Hubbs and Bartholomew (1952) found none there in 1950, but they did not examine the west coast. We saw 36 elephant seals hauled out on a small beach on the west side of the island 1 km. south of the north end; we were too far offshore to see if any pups were present. Eleven solitary males were seen around the north end of the island.

Over 90 per cent of all breeding northern elephant seals breed on Guadalupe and the Benitos. Elsewhere, elephant seals breed or regularly haul out on the Islas Los Coronados, Baja California, and on Santa Barbara, San Nicolas, San Miguel, Santa Rosa, and Anacapa islands of the Channel Islands off southern California. In central California, they have recently established a rookery on Año Nuevo Island north of Santa Cruz, and they sometimes haul out on the Farallon Islands, on Point Reyes, and on Seal Rock near Monterey (Radford, Orr, and Hubbs, 1965). Studies now under way by George A. Bartholomew in the Channel Islands, and by the Stanford Research Institute on Año Nuevo Island (Orr and Poulter, 1962, 1965), along with our observations, provide a census of the total elephant seal population in January-February, 1965 (table 3). The counts total 9,221 adults and 4,851 pups, for a total of over 14,072 on all known rookeries and hauling grounds. To this number may

Fig. 5. The carcasses of at least 25 elephant seal pups are visible here on the landward side of the North Barracks Beach rookery, Isla Guadalupe, January 28, 1965. (KWK 65-2-18)

be added 20 per cent (Bartholomew and Hubbs, 1960) as a conservative estimate of the animals, mostly immature, at sea, for a grand total of about 17,000 at the high point of the year. This value may be compared with the Bartholomew and Hubbs (1960) estimate of 15,000 animals in 1960. In summary, the population of northern elephant seals seems to have leveled off on Isla Guadalupe, but elsewhere this species is still expanding its range and increasing its numbers.

Guadalupe Fur Seals. — We counted 285 fur seals on Isla Guadalupe. Fur seals regularly occupy only a 13 km. sector of the eastern shore of Guadalupe. We covered this entire sector on foot, except for the northernmost 2 km. (a section with very few seals), which we surveyed from a small boat. We also covered by small boat at least 1 km. of shoreline to the north and south beyond the last observed seals. Although we may have missed a few seals that were hidden behind boulders, we believe that the total number of animals hauled out at the time of our visit did not exceed 300.

In 1950, Bartholomew and Hubbs (1952), despite a careful search by small boat along most of the east coast, failed to find any fur seals on Isla Guadalupe, and the species was thought to be extinct. A few fur seals must have been present at that time, but the population was certainly much smaller than now. The east shore of the island was closely navigated by small boat everywhere except along the very sector where the fur seals now occur, as shown on fig. 1 (Hubbs, *in litt.*). The species was rediscovered in November, 1954, by Hubbs (1956), when 14 fur seals were located at the northernmost point of their present range, after none were seen in running close along the entire east coast from the south end to the point

TABLE 2

Details of 1965 pinniped censuses on Islas Guadalupe, San Benito, and Cedros.

The area numbers refer to the maps (figs. 1-3).

Area	Date	*Mirounga*		*Arctocephalus*	*Zalophus*
		1 year old and older	Pups		
Isla Guadalupe					
1	Jan. 28	2,700	1,550[1]		
2	" "	18			
3	" "	97	56[1]		
4	" "	37			
5	" "	1,255	720[1]		
6	" "	55			
7	" "	1,100	631[1]		
8	" "	35			
9	" "	7	3		
10	Jan. 29			8	
11	" "			17	
12	" "			184	
13	" "			25	
14	" 30			41	
15	" 28	19	9		
16	" 30			10	
17	" 28	1			
18	" "	28	10		
19	" 31	169			
20	" "	1,200	689[1]		
I. Zapato	" 30				585
Totals		6,721	3,668	285	585
Isla Benito del Oeste					
1	Feb. 2	19	7		24
2	" "	6			29
3	" "	148	58		85
4	" "	190	74		100
5	" "	29	14		338
6	" "	64	7		559
7	" "	13			115
8	" "	7	1		325
9	" "	50	24		270
10	" "	235	116		335
11	" "	61	22		275
12	" "	43	14		113
13	" "	7			
14	" "	1			
15	" "				
16	" "	84	39		
17	" "	10			28
Totals		967	376		2,596

TABLE 2 (Continued)

Area	Date	*Mirounga*		*Arctocephalus*	*Zalophus*
		1 year old and older	Pups		
Isla Benito del Centro					
1	Feb. 2	79	No data		456
2	" "	14	"		230
3	" 3	208	"		885
4	" "	132	"		415
5	" "	14	"		145
6	" "	1	"		105
Totals		448	174[1]		2,236
Isla Benito del Este					
1	Feb. 2	3	No data		136
2	" "	2	"		134
3	" "	1	"		72
4	" "	1	"		102
5	" "	51	"		337
6	" "	16	"		111
7	" "	46	"		255
8	" "	1	"		68
9	" "	12	"		96
10	" "	161	"		335
11	" "	342	"		404
12	" "	9	"		276
Totals		645	250[1]		2,326
Isla Cedros					
1	Feb. 3				1,340
2	" "	3			1,396
3	" "	43			1,441
4	" "	1			4,230
5	" "			3	
Totals		47		3	8,407

[1]Calculated number; see text.

of discovery (Hubbs, *in litt.*). Counts made between 1954 and 1963 are not fully comparable with our count, because along most of the shore they were made from small boats, rather than by consistently walking the shoreline. We have found that observers in small boats miss many seals. The shoreline of Guadalupe where the seals haul out is largely a jumble of enormous, blackish boulders, of essentially the same color as the seals, at the foot of rugged volcanic cliffs that are undercut by many sea caves. The seals are scattered singly and in small groups, and hide in the caves and in the crevices and tide-pools beneath and behind the boulders and ridges. Many seals can be found only by an observer on shore who carefully searches all these hiding places. However, the repeated censuses by parties from Scripps Institution of Oceanography have definitely shown a marked increase, because many more have been seen recently from a skiff than were formerly observed (Hubbs, *in litt.*).

TABLE 3

World population of the northern elephant seal in 1965.

Island	Year reoccupied[1]	Population in 1965			Authority[2]
		1 year old and older	Pups	Total	
Isla Guadalupe		6,721	3,668	10,389	Present paper
Islas San Benito	1918	2,060	800	2,860	Hanna, 1925; present paper
Isla Cedros	1965	47	0	47	Present paper
Islas Los Coronados	1948	1	0	1	Bartholomew, 1950; present paper[3]
Santa Barbara Island	1948	4	0	4	Bonnot, 1951; present paper[4]
San Nicolas Island	1949	No data	No data		Bartholomew, 1951
San Miguel Island	1925	252	311	563	Rett, 1952; present paper[5]
Santa Rosa Island	1965	?	14	14	Present paper[6]
Anacapa Island	1958	No data	No data		Bartholomew and Boolootian, 1960
Año Nuevo Island	1955	136	58	194	Orr and Poulter, 1962; Jennings, *in litt.*[7]
Totals		9,221	4,851	14,072	

[1]Year of first published observation; reoccupation may have occurred somewhat earlier. In most localities the year of first breeding is unknown.
[2]Where two references are cited, the first refers to the year of reoccupation, the second to the 1965 population.
[3]Incomplete count made March 15 by Rice.
[4]Count made March 20 by Balcomb.
[5]Count made March 20 and 21 by Balcomb.
[6]Count made April 11 by Balcomb.
[7]Count made January 30 by Jennings.

Three other counts are comparable with ours, having been made on foot. Lluch and Pilson (Lluch, Irving, and Pilson, 1964) found 240 seals in February, 1964. Hubbs (*in litt.*) and party counted 252 in November, 1964, and 211 in March, 1965.

About two-thirds of the seals that we saw appeared to be less than a year old. Some were very small, though none had black natal pelage. Analogy with the northern fur seal, *Callorhinus ursinus*, suggests that the breeding season had terminated at least 15 weeks previously (Bauer, Peterson, and Scheffer, 1964). The only published observations on the breeding season of the Guadalupe fur seal are Scammon's (1874) statement that they bring forth their young between May and August on the California coast, and Townsend's (1899) reference to an unnamed sealing vessel in 1880 that "reported that the young were born about the middle of June" on Guadalupe. These observations agree with those of parties from Scripps Institution (Hubbs, *in litt.*).

Because of the scarcity of adults, especially males, we believe that most of them were at sea at the time of our count. We saw several individuals at sea within 22 km. of the island, and on January 31 Balcomb identified one at 29°16′ N, 117°24′ W, 88 km. ENE from Guadalupe. A. W. Anthony (in Thoburn, 1899) wrote: "In conversation with those who sealed there [Guadalupe] when the species was common I learn that the old bulls left the females and pups as soon as the latter were a week or so old, and were not seen again until the following year. It is thought that they go to sea . . . ." In the northern fur seal, young of the year constitute about one-third of the population (Kenyon, Scheffer, and Chapman, 1954). If the same holds true for the Guadalupe fur seal, 200 young animals would suggest a total population of about 600. The population seems to be entering a phase of rapid logarithmic growth.

At Isla Cedros on February 3, 1965, we observed three Guadalupe fur seals in shallow water 25 m. off the beach about half way down the eastern shore. None was hauled out. On March 12 and 13, 1965, Rice revisited the site and saw possibly 10 small otariid seals in the

water near the beach. Because they were very shy, and surfaced only momentarily, it was impossible to ascertain whether they were fur seals or young sea lions. At least 10 km. of the adjacent shoreline was carefully scrutinized, but no animals were hauled out. Prior to our visit, fur seals had not been found on Cedros for over a century. We do not know whether these fur seals represent a resident colony or whether they are wanderers from Guadalupe.

California Sea Lions. — Sea lions breed during the summer; at the time of our counts, the young of the year were well grown and we did not attempt to record them separately. Our counts of sea lions, compared with the 1950 counts of Bartholomew and Hubbs (1952), revealed an increase from 165 to 585 in the population at Islote Zapato off Isla Guadalupe, a decrease from 9,700 to 7,200 at the Islas San Benito, and an increase from 340 to 8,400 at Isla Cedros (the count for Cedros in 1950 included only the east shore). The total for all these islands had increased from about 10,000 to about 16,000.

One possible explanation is that the San Benito population, following heavy exploitation in 1939, has increased enough to occupy all the available habitat, and that the surplus animals have moved to Cedros. Other possibilities are that California sea lions may alternately use several different hauling grounds, or that they spend variable periods at sea and on shore. On March 13, 1965, on the east side of Cedros south of the north lighthouse, Rice counted only 2,850 sea lions, compared with 5,671 in the same area 38 days earlier.

The seasonal movements of California sea lions are poorly understood. As did Bartholomew and Hubbs (1952), we found few adult males. Many adult males move north during the winter. Over 10,000 males annually congregate at that season on Año Nuevo Island near Santa Cruz, California, north of the breeding range of the species (Orr and Poulter, 1965), and a few males are seen regularly in winter as far north as Sea Lion Caves, Oregon (Kenyon and Scheffer, 1962; Rice, unpublished field notes), and occasionally off Washington (Kenyon and Scheffer, 1962) and Vancouver Island, British Columbia (Cowan and Guiguet, 1956). Some adult males remain in the south, however, as we saw several at sea; we also saw one hauled out at Cabo San Lucas, the southern extremity of the present range of the species. Hubbs (*in litt.*) has found that Isla Guadalupe is often invaded in the winter by adult males, possibly from the San Benitos. At Guadalupe, as elsewhere, however, we saw very few adult males.

SUMMARY

We made a census of northern elephant seals, *Mirounga angustirostris*, Guadalupe fur seals, *Arctocephalus philippii townsendi*, and California sea lions, *Zalophus c. californianus* on Isla Guadalupe, the Islas San Benito, and Isla Cedros, Baja California, Mexico, between January 28 and February 3, 1965, exactly 15 years after a similar census by Bartholomew and Hubbs. According to our counts and estimates, there were 6,700 elephant seals older than one year and 3,700 pups on Guadalupe; 2,100 older animals and 800 pups on the San Benitos; and 47 adults on Cedros. The population appears to have leveled off on Guadalupe; crushing of pups on overcrowded rookeries may be one factor. Elephant seals are increasing on the San Benitos, and were found on Cedros for the first time in recent years. The world population is about 17,000. We counted 285 fur seals on Guadalupe, and 3 at Cedros; as far as is known they breed only on Guadalupe. With an allowance for adults at sea, the total fur seal population is estimated at 600, and it appears to be rapidly growing. We counted 585 sea lions on Guadalupe, 7,200 on the Benitos, and 8,400 on Cedros.

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eprinted from Transactions of the Thirtieth North American Wildlife and Natural Resources Conference, March 8, 9 and 10, 1965. Published by the Wildlife Management Institute, Wire Building, Washington 5, D. C.

ADIOISOTOPE TECHNIQUES IN FISHERY RESEARCH

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Many new research possibilities have arisen in the field of fishery iology as radioactive tracers have become available. The high sensi- vity of instruments used to measure radioactivity has made ossible the application of tracers to problems beyond the range of andard methods. Also, the radioisotopic tracer furnishes a means or quantitative determination of biological substances without uantitative isolation. Radioisotopes afford an extremely useful eans for: (1) measuring primary productivity; (2) following ycling of trace metals; (3) tracing movements of pollutants, sedi- ents, organisms, and water; (4) studying the physiology, foods, nd feeding of fish and shellfish; and (5) using radiation to modify species through genetic mutation, eradicate undesirable or noxious ecies, and cure disease. In addition to knowledge gained from the xperimental introduction of tracer amounts of radioisotopes into

[1]Research jointly sponsored by the Atomic Energy Commission.

restricted areas of the aquatic environment, much information on the accumulation of certain radioisotopes by organisms has been obtained from fallout radioactivity. Also, by tracking radioisotopes in nuclear reactor effluents, the cycling of specific radioisotopes can be delineated. An excellent review on the use of radioisotopes in hydrobiology and fish culture was published by Hooper, Podoliak, and Snieszko (1958).

MEASURING PRIMARY PRODUCTIVITY WITH RADIOACTIVE CARBON

A new method for the measurement of primary productivity with carbon 14 became available with the production of radioisotopes (Steemann Nielsen, 1952 and Strickland, 1960). This method is 50 to 100 times as sensitive as the light- and dark-bottle oxygen method and permits rapid, convenient measurements in areas of low primary productivity. Its use also is advantageous in highly productive areas because less time is required for measurements. By this method the rate at which energy is accumulated in the form of organic matter can be calculated from the net mass of carbon fixed per unit of time per unit volume of water.

The basic methodology is relatively simple. Samples of water to be used for measuring productivity are collected from various depths in a nonmetallic container such as a Van Dorn water sampler (Figure 1). The water is siphoned into Pyrex bottles similar to those

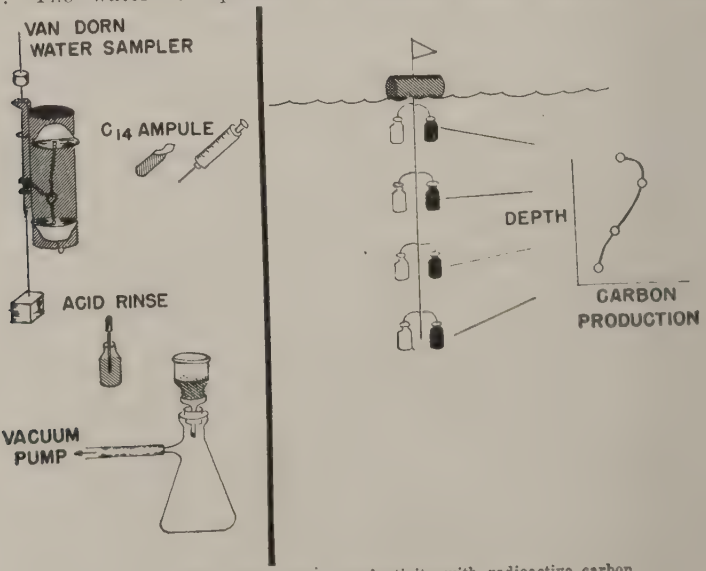

Figure 1. Measuring primary productivity with radioactive carbon

suspended from the buoy. A known amount of carbon 14 as bicarbonate is added to the bottles with a syringe. The uptake of carbon 14 by nonphotosynthetic processes is measured in a second sample, similarly prepared, but kept in a black bottle. The bottles can be suspended in the water at the depths from which the samples were taken or illuminated under standard conditions in the laboratory or on shipboard. After a period of time that usually does not exceed 24 hours, the water is filtered through a fine filter (usually an HA Millipore Filter with a 0.45 μ porosity). The cells retained on the filter are then washed with 10 to 20 ml. of a 0.001 to 0.002 N hydrochloric acid solution in 3.5 percent sodium chloride, to dissolve and remove carbon 14 which may be retained on the filter as an inorganic carbonate. The filter is given a final wash with a neutral electrolyte to remove all acid and is then dried. The amount of carbon 14 on each filter is determined with a counter for measuring radioactivity. From these measurements the carbon 14 fixed at each depth is calculated by subtracting uptake values in the dark bottle from those in the light bottle. Carbon 14 and carbon 12 are fixed in proportion to their concentrations, and the amount of carbon 12 fixed per unit volume can then be found from the following relationship:

$$C^{12}_{F} \doteq \frac{C^{12}_{A}\, C^{14}_{F}}{C^{14}_{A}}$$

C^{12}_{F} = carbon 12 fixed

C^{12}_{A} = carbon 12 available

C^{14}_{F} = carbon 14 fixed

C^{14}_{A} = carbon 14 available

These results plotted for each depth sampled yield a photosynthetic profile. The rate of carbon fixation per unit surface area can be determined from the area under this profile.

FOLLOWING THE CYCLING OF TRACE ELEMENTS WITH RADIOISOTOPES

The cycling of some trace elements which may control productivity can be followed with radioisotopes (Figure 2). The fertility of both fresh and salt water is of interest to fishery biologists, since productivity and production of fish are related to the nutrient content

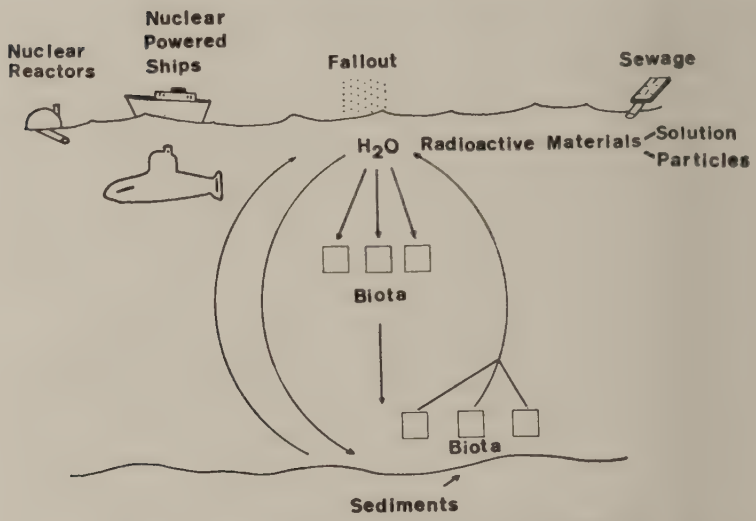

Figure 2. Following the cycling of elements with radioisotopes

of the water. Expectation of increased yields from the application of fertilizer to certain waters has stimulated many biologists to study the feasibility of artificially enriching water with some essential elements. In such instances the addition of radioisotopes to the fertilizer can provide an effective means for following specific elements.

Radioactive materials introduced into an aquatic environment can: (1) remain in solution or in suspension, (2) precipitate and settle on the bottom, or (3) be taken up by plants and animals. Cycling can be expressed as the three R's: routes, rates, and reservoirs. Each element, as well as each radionuclide, follows a characteristic route and has its own rate of movement from component to component or from reservoir to reservoir. Three reservoirs exist in an aquatic environment: water, sediment, and biota. Elements and radioisotopes can move from the water to the sediments or to the biota. In effect, the sediments and biota compete for isotopes in the water.

Pathways and cycling of nutrient chemicals in lakes and ponds have been studied by adding radioactive tracers to the water (Hutchinson and Bowen, 1950; Rigler, 1956; and Hasler, 1957). Similar studies have been carried out in estuaries by members of the staff of our laboratory. Although several different radioisotopes could serve in this type of study, phosphorus 32 has been used most

frequently. Characteristics which have contributed to the use of this radioisotope are: its short half-life, making it relatively safe in field experiments; its role as a nutrient element, resulting in its rapid uptake by bacteria and phytoplankton; and its eventual appearance in almost every type of organism present in the water.

TRACING MOVEMENT OF POLLUTANTS, SEDIMENTS, ORGANISMS, AND WATER WITH RADIOISOTOPES

The movement of both animate and inanimate substances can be followed by labeling them with radioisotopes (Figure 3). The dispersion of pollutants in the natural environment has been followed by adding radioisotopes to the substances (Simpson, Beetem, and Ruggles, 1958). Also, radioisotopes have been used to trace the Los Angeles City sewage effluent into Santa Monica Bay (Pearson, 1959).

The capacity of sediments to sorb radionuclides from water can be used in many ways by the investigator. Engineers now label sediments with radioactive gold to determine sedimentation rates, to locate and measure bottom scouring, and to follow sediment transport in bays and estuaries. Labeled sediments can help ecologists follow the "silting in" of bottom fauna and the transport of substrates. With this information the most favorable location for shellfish beds can be determined.

Although sediments are not often included in the food web of marine organisms, some bottom feeders evidently use organic materials in sediments as a source of nourishment. Many organisms, for example the penaeid shrimp of the Gulf of Mexico, periodically move to inshore areas, remain for a short time, then return to offshore waters. It has been suggested that while in the estuary the shrimp feed on the organic matter contained in the sediment. Laboratory experiments in which sediments containing radioactive organic material are fed to shrimp would yield information on the extent to which this sediment-sorbed material is used.

Marking or tagging methods have been used for many years to

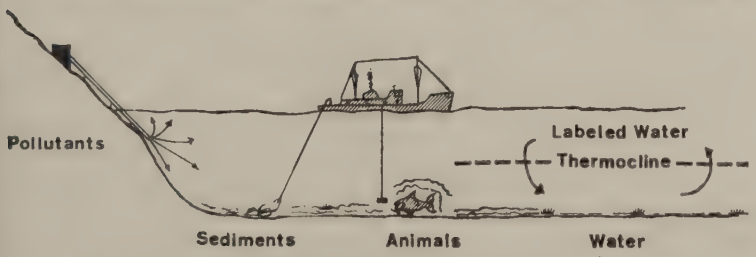

Figure 3. Tracing movement of animals and substances with radioistopes

study the movement, migration routes, growth rates, mortality rates, and other aspects of the life history of organisms. Radioisotopes are among the many new methods of tagging fish which have been considered (Seymour, 1958). Recently the Bureau of Commercial Fisheries has tagged herring with an internal magnetic tag in an attempt to develop a radioisotopic tag. To improve the "tagging method" several factors must be considered, such as the ease of applying the tag, its effect upon the animal, its permanency, the ease of detecting the tag for recovery, and the cost of tagging and recovery. To be suitable for use as a tag, a radioisotope should be a gamma emitter with a high energy and a long physical half-life. If used as a tag in a tissue, it should be concentrated to high levels and have a long biological half-life. Much more research with several different types of animals is needed before it can be stated whether radioisotopes have certain advantages over other tags.

Nuclear detonations in the Pacific afforded the first opportunity to trace water masses contaminated with radioactive materials. The technique of following water movement by adding a radioisotope has been used frequently since that time. The advantage of a radioisotope is that even the small quantities that remain after tremendous dilution can be measured accurately. Vertical mixing, direction and rate of water movement, and possibly flushing rates in estuaries can be followed with radioisotopes.

Study of the Physiology, Foods, and Feeding of Fish and Shellfish with Radioisotopes

Radioisotopes afford an extremely valuable means for following the absorption and transport of materials in marine organisms and for elucidating metabolic reactions and transfer rates (Figure 4). Even though it was recognized that many body constituents of fish were continually undergoing simultaneous formation and degradation, it was difficult to demonstrate this action before radioistopes became available (Baptist and Price, 1962). For example, exchange now can be measured by the transfer of radioactive atoms even when there is no net chemical change. Radioisotopes of elements in biological systems, such as hydrogen, carbon, and phosphorus have found increasing application as "tracers." Their use in the identification of intermediate compounds and the qualitative description of biochemical pathways and reaction mechanisms has resulted in unprecedented advances. Further, studies of transfer and turnover rates of substances in living systems now can be carried out with radioisotopes.

Radioisotopes also may be used advantageously to obtain answers

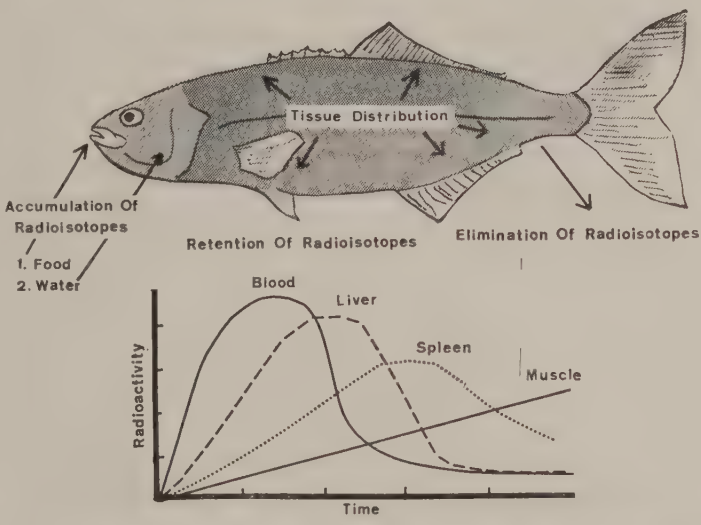

Figure 4. Studying the physiology of fish with radioisotopes

to some of the problems in the study of foods and filter feeding of primary consumers (Figure 5). Before radioisotopes became available it was difficult to compare the suitability of different species of phytoplankton as food for the clam, *Mercenaria mercenaria* (Rice and Smith, 1958). To make such a comparison without radioisotopes required that one species of phytoplankton be fed to a clam at a time. It was assumed that the clam always would feed at the same rate under identical conditions. In our laboratory we found, however, that the same clam did not always filter cells of a species from the water at the same rate, even though the concentration of cells and other factors were duplicated. Consequently, meaningful comparisons could not be made between different species of phytoplankton fed to the clam at different times.

It was found that the suitability of two species of phytoplankton could be compared if they were labeled with different radioisotopes and fed to the clam at the same time. The filtering rate for each species could be followed simultaneously. One species of phytoplankton was labeled with phosphorus 32 and the other with calcium 45 (Smith, 1958). The radioactivity of each of these isotopes could be determined in the presence of the other. After growing

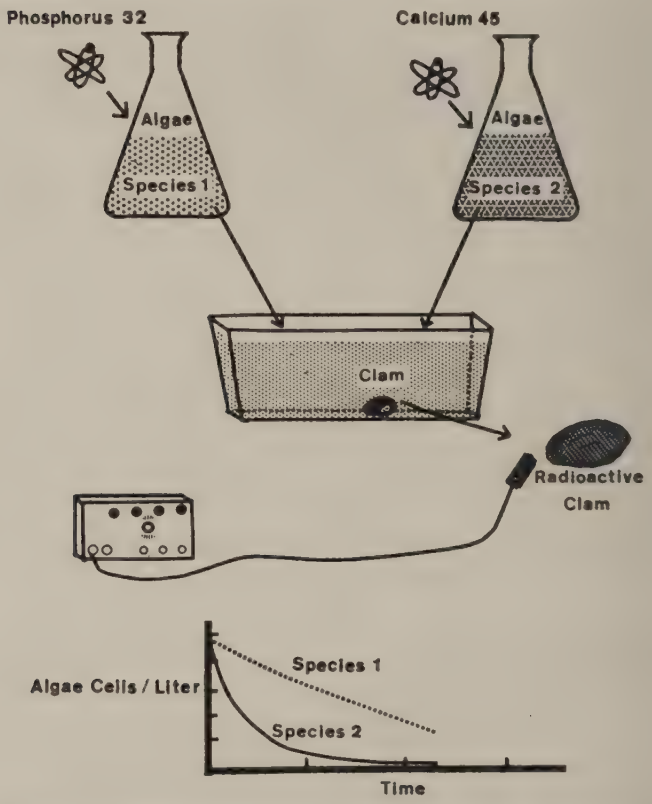

Figure 5. Determining filtering rates of clams with radioactive phytoplankon

cells in medium with radioactivity for several days, the amount of phosphorus 32 per cell of one species and calcium 45 per cell of the other species was determined. The cells from the two cultures then were mixed in sea water, a clam was placed in the water, and the rate of filtering was determined for each species. It was shown that the clam can remove phytoplankton cells of different species at different rates. Selectivity is based on the size and chemical characteristics of the cells.

THE USE OF RADIATION FROM RADIOISOTOPES

Man has been confronted continually with the problem of introducing animals to new regions or of replacing a declining stock with

a more resistant species. In recent years two outbreaks of disease caused by the microorganisms *Dermocystidium marinum* and MSX have greatly reduced the population of oysters along the Atlantic Coast. In relation to these problems and others, much thought has been given to the possibility of developing more resistant strains, as is done in the breeding of farm animals.

The field of radiation genetics has grown rapidly since 1927, when Müller discovered that the rate of mutation can be increased in the fruit fly by X-ray irradiation. At our laboratory we are determining effects of radiation on marine organisms (Figure 6). Radiation can affect not only the organism being irradiated, but also the progeny of the organism, by genetic mutation. Not all mutations are necessarily detrimental. Increasing the mutation rates in plants by irradiation has enabled plant geneticists to produce more desirable strains of corn, wheat, and various flowering plants. Thus, it is conceivable that irradiation and selection may be applied to the breeding of marine organisms, to develop new strains that can successfully withstand the rigors of a changing environment. The new strains may enable us to produce fishery products in greater quantity or of better quality.

Irradiation also can be used to eradicate certain undesirable or noxious species and possibly to cure disease. The classical example of such an eradication is the elimination of the screwworm fly in the southeastern United States. This pest was eradicated in less than 2 years over an area of 70,000 square miles by weekly releases of male screwworm flies that had been sterilized by irradiation with cobalt

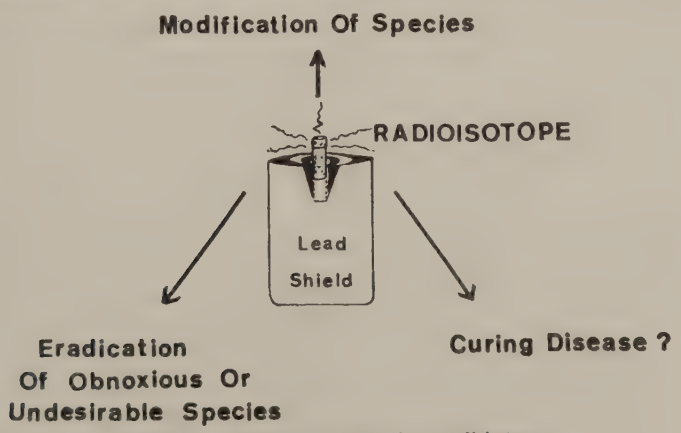

Figure 6. Utilizing radiation from radioisotopes

60. Although this method of eradication has not been particularly successful with marine species in a few preliminary attempts, the accumulation of more knowledge on the effects of radiation on marine organisms will improve the likelihood of success in the future. Radioisotopes have been used on a large scale by the medical profession during recent years to cure disease. A number of observations also have been made of the effects of radioisotopes or aquatic organisms. Iodine 131 destroyed the diffuse thyroid tissue of the Atlantic salmon (LaRoche and Leblond, 1954). Although this was a physiological study, it suggested the need to investigate the possibility of curing certain diseases of aquatic organisms with radioisotopes.

CONCLUSION

I hope you have not been led to believe that I am of the opinion that all fishery problems can be solved with radioisotopes. It is my firm conviction, however, that many unsolved fishery problems will yield to radioisotopic techniques. It is my further prediction that radioisotopes will become increasingly important in fishery research in the future.

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DISCUSSION

MR. GEORGE EICHER (Portland, Oregon): I would like to know if anyone who so desired can purchase or make use of radioactive materials?

DR. T. R. RICE: Not necessarily. Anyone who uses radioactive materials must obtain a license from the Atomic Energy Commission. To obtain this license you must show the Commission that you have training in the use of radioiostopes and that your laboratory facilities are adequate for this usage. However, outside of this, it is possible to purchase certain small quantities of C-14 and some other materials without going through the Commission for it.

DR. TONY PETERLE (Ohio State University): What problems do you encounter using double isotopes—two different isotopes in individual organisms in terms of biological change? In other words, what are the problems connected with double labels?

DR. RICE: Thus far we have not run into any problems. When two radioisotopes are present in an organism neither isotope affects the metabolism of the other under experimental conditions. If the total amount of activity is not sufficient to injure the animal, then there should be no complications from having two isotopes present in an animal at one time.

MR. GEORGE SPRECHER (Wisconsin): I would like to ask Dr. Rice how he disposes of his radioactive animals.

DR. RICE: As specified in the license, we not only have permission to use them but authority to dispose of our radioactive material in the ocean, at a specified place. We must dispose of this material first by dicing the animals, and dissolving their tissues through the use of acids. As a result, once they are added to the sea water, they are dissipated to an infinitesimal quantity so that they can have no subsequent effects upon sea food or man.

VICE CHAIRMAN SCHONING: Ted, you have presented some interesting and stimulating information for the thinking of the audience, as indicated by some of the questions they have answered.

Reprinted from

HEALTH PHYSICS

Official Journal of the Health Physics Society

PERGAMON PRESS

OXFORD • LONDON • NEW YORK • PARIS

Health Physics Pergamon Press 1965. Vol. 11, pp. 953–964. Printed in Northern Ireland

THE ROLE OF PLANTS AND ANIMALS IN THE CYCLING OF RADIONUCLIDES IN THE MARINE ENVIRONMENT

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(*Received* 18 *June* 1964; *in revised form* 5 *October* 1964)

Abstract—Plants and animals have a capacity, which varies from species to species, for concentrating specific radionuclides. The level to which an isotope is concentrated by any organism can vary with season, geographical location and other factors not completely understood at this time. Plants and animals play an important role in the cycling of radionuclides in the sea not only while living, through metabolism, but also after death, through the process of decomposition.

The availability of radionuclides to marine organisms is dependent to a large extent upon the physical state in which the isotopes occur in seawater. Both particulate and dissolved radionuclides can enter into the biogeochemical cycles of the marine environment. These materials can: (1) remain in solution or in suspension, (2) precipitate and settle on the bottom or (3) be taken up by plants and animals. Immediately upon introduction of radioactive materials into the water, certain factors interact to dilute and disperse these materials, while simultaneously other factors tend to concentrate the radioactivity. Radioactive materials upon introduction into the marine environment may be cycled through the following three components: water, sediment and biota. This cycling can be described by the three R's: routes, rates and reservoirs.

Each radionuclide takes a characteristic route and has its own rate of movement from component to component prior to coming to rest in a reservoir, one of the three components of the marine environment. Plants and animals to be of any significance in the cycling of radionuclides in the marine environment must accumulate the radionuclide, retain it, be eaten by another organism and be digestible. Organisms can obtain radioactivity by absorption, adsorption and ingestion. Conversely, radionuclides may be lost by excretion and decomposition. Sediments may accumulate radionuclides through the physical processes of exchange and adsorption. Water acts as the principal medium of transport between the biota and sediments.

Seafood organisms that contain radioactivity are a potential health hazard to man. The extent of this hazard depends upon the amount of radioactivity concentrated in the edible tissues of the organisms. Fish and shellfish are among the marine animals of greatest concern from the standpoint of public health. It is important to determine the accumulation of the different radionuclides by the various marine organisms in order to identify those that can serve as "biological indicators." Biological indicators are defined as those organisms concentrating relatively large amounts of specific radionuclides making it possible to detect the presence of minute amounts of these isotopes in the environment through an analysis of the organisms.

* The Radiobiological Laboratory is jointly supported by the Bureau of Commercial Fisheries and the Atomic Energy Commission.

The seas are vast and the possibilities for dispersion of radionuclides are enormous. However, there has been great concern over the release of radioactive materials into the marine environment. Those who oppose this release of radioactivity are concerned about the possibility of the return to man of isotopes through harvesting of the living resources from the sea. No doubt all plants and animals have a capacity, which varies from species to species, for concentrating specific radionuclides. The level to which an isotope is concentrated by any organism can vary with season, geographical location and other factors not completely understood at this time.

Plants and animals play an important role in the cycling of radionuclides in the sea not only while living, through metabolism, but also after death, through the processes of decomposition. In contrast with inanimate objects which may physically adsorb small amounts of radioactivity, the biota has the capacity to accumulate some radioactive elements thousands of times over the amounts present in seawater. In addition, many bottom-dwelling animals are capable of accumulating radioactivity from the sediment. The accumulated elements may be incorporated into new compounds which are either excreted and subsequently re-cycled, or transmitted directly to other organisms through the food web. Even after death, the biota are involved in the cycling process. Dead tissues are attacked by bacteria and other organisms which decompose them to their component elements. These elements become available as nutrients for the production of new organic material. Organisms not only cycle elements in a local environment, but some animals transport elements great distances during migration. This is particularly true of pelagic fishes such as the tuna. Contaminated tuna[1] were caught near Japan 5 months after the Bikini test of 1 March 1954.

PHYSICAL STATE OF RADIONUCLIDES IN SEAWATER

The availability of radionuclides to marine organisms is dependent to a large extent upon the physical state in which the isotopes occur in seawater. Radionuclides may find their way into the marine environment in the particulate or dissolved state. Those isotopes introduced as particles may dissolve or remain particulate while those introduced in the dissolved state may be sorbed onto particulate matter, may form colloids, may precipitate as particles or may remain in solution. Both particulate and dissolved radionuclides can enter into the biogeochemical cycles of the marine environment. The physical states of fission produced elements have been determined by Greendale and Ballou[2] in laboratory experiments designed to simulate an underwater nuclear explosion. They predicted the physical states of fission product elements and had their predictions partially confirmed by field observations. The states of fission product elements following their vaporisation in seawater are given in Table 1.

Table 1. Physical states of elements in seawater[2]

Element		Percentage in given physical state		
		Ionic	Colloidal	Particulate
Cs	Cesium	70	7	23
I	Iodine	90	8	2
Sr	Strontium	87	3	10
Sb	Antimony	73	15	12
Te	Tellurium	45	43	12
Mo	Molybdenum	30	10	60
Ru	Ruthenium	0	5	95
Ce	Cerium	2	4	94
Zr	Zirconium	1	3	96
Y	Yttrium	0	4	96
Nb	Niobium	0	0	100

FACTORS DILUTING AND CONCENTRATING RADIONUCLIDES

Radioactive materials introduced into a marine environment can: (1) remain in solution or in suspension," (2) precipitate and settle on the bottom or (3) be taken up by plants and animals. Immediately upon introduction of radioactive materials into the water, certain factors interact to dilute and disperse these materials, while simultaneously other factors tend to concentrate the radioactivity (Fig. 1). Among those factors which dilute and disperse radioactivity are currents, turbulent diffusion isotopic dilution and biological transport.

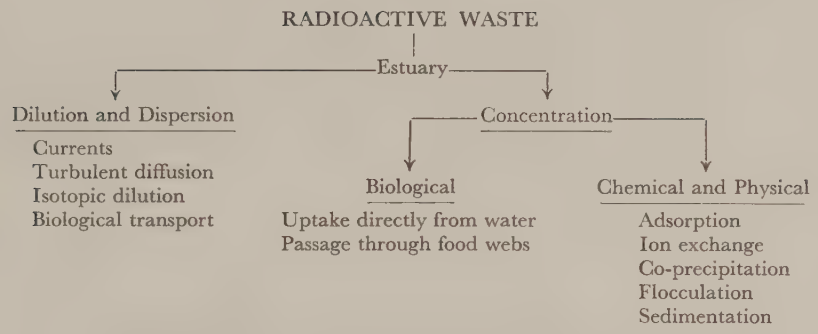

Fig. 1. A schematic diagram showing the processes tending to dilute or concentrate radioactive materials added to a marine environment.

Concentrating factors are biological, chemical and physical. Radioactivity is concentrated by the biota by uptake directly from the water and passage through food webs; chemically and physically by adsorption, ion exchange, co-precipitation, flocculation and sedimentation.

COMPONENTS OF MARINE ENVIRONMENT

Radioactive materials upon introduction into the marine environment may be cycled through the following three components: water, sediment and biota (Fig. 2). This cycling can be described by the three R's: routes, rates and reservoirs. Each radionuclide tends to take a characteristic route and has its own rate of movement from component to component prior to coming to rest in a temporary reservoir, one of the three components of the marine environment. Isotopes can move from the water to the sediments or to the biota. In effect the sediments and biota compete for the isotopes in the water. Even though in some instances sediments are initially successful in removing large quantities of radionuclides

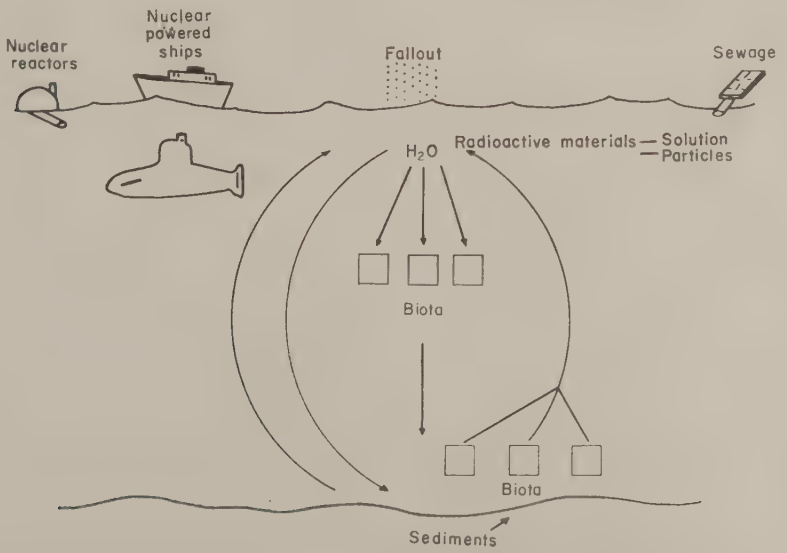

Fig. 2. Sources of radioactive pollution and the cycling of radionuclides in the marine environment.

from the water and thus preventing their immediate uptake by the biota, this sediment associated radioactivity may later affect many benthic species by exposing them to high levels of radiation. Also, any radioactivity leached from the sediments back to the water again becomes available for uptake by the biota. Even before the radioactivity is leached from the sediment it may become available to the biota, due to a variation in the strength of the bonds between the different radionuclides and the sediment particles. Loosely bound radionuclides can be "stripped" from particles of sediment and utilized by bottom-feeding organisms.

COMPARISON OF ESTUARINE AND OCEANIC HABITATS

Differences between estuarine and oceanic habitats should be considered since we are concerned primarily with possible instances of acute pollution in estuaries. One of the differences is that in the open ocean a radionuclide would tend to be diluted rapidly in a water mass and dispersed, whereas in the estuary it would tend to be concentrated by biological and physicochemical processes. A second difference is related to the relative shallowness of the estuary. The sediment and the exchange of radionuclides between the sediment and associated benthic community are factors that must be considered in estuaries. However, due to thermal stratification, depth of water and circulation patterns, the sediment and benthic community in the ocean are relatively unimportant in the cycling of radionuclides. In the ocean, elements that are exchanged between the sediment and water may take thousands of years to reach the surface waters. A third difference is that food chains in the sea are relatively simple in comparison with those of the estuary. The food chain of the sea is based on phytoplankton while food chains in estuaries are based on both benthic plants and phytoplankton.

Therefore, the benthic as well as the pelagic community must be considered in estuaries. The producers of the benthic community are algae that grow on or are attached to the sediment and rooted phanerogams. The animal community is composed of the epifauna (animals living on the sediment surface) and the infauna (animals living within the sediment). Also associated with the sediments are the decomposers, bacteria and fungi, which are instrumental in the decay and mineralisation of organic materials.

BIOTA

Plants and animals to be of any significance in the cycling of radionuclides in the marine environment must accumulate the radionuclide, retain it, be eaten by another organism and be digestible. However, if an organism accumulates and retains a radionuclide and is not eaten but dies, the radionuclide will even under these conditions enter the "biological cycle" through organisms which decompose the dead organic material into its elemental components.

The biota can obtain radioactivity by absorption, adsorption and ingestion (Fig. 3). Conversely, radionuclides may be lost by excretion and decomposition. Sediments may accumulate radionuclides through the physical processes of exchange and adsorption. Water acts as the principal medium of transport between the biota and sediments.

Even though sediments may form the chief reservoir for trace metals in an estuary, the benthic organisms profoundly influence the exchange of trace metals between sediment and water. For example, a film of bacteria and microscopic algae commonly coats the sediment of shallow water. The exchange of zinc-65 between sediments and water was compared in the laboratory under three conditions: in an illuminated container which served as a control; in a darkened container; and in a container in which the contents were rendered sterile. In the darkened container, which eliminated photosynthetic organisms, the rate of zinc exchange was $\frac{2}{3}$ that of the control. Elimination of all organisms reduced the rate of zinc exchange to $\frac{1}{3}$ that of the control. Also, the burrows of worms and other benthic infauna extends the sediment-water interface to considerable depths into the sediment. This burrowing increases the interface area, the exchange of trace metals and their radionuclides, and permits a more rapid exchange between the water and deeper sediments.

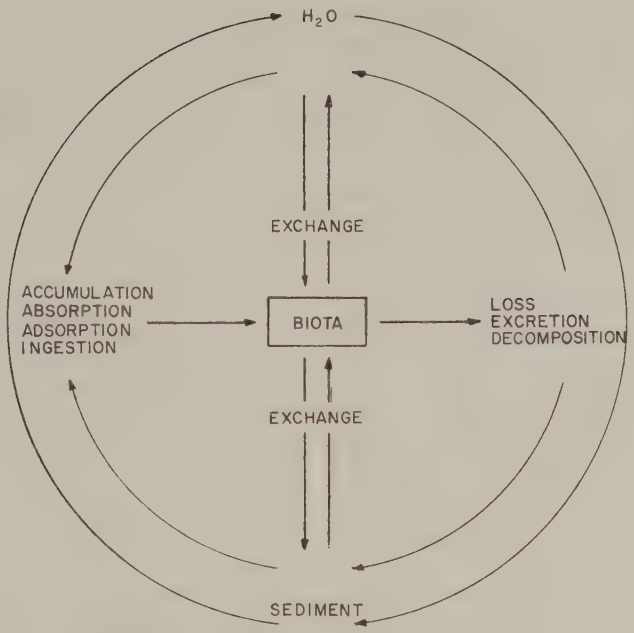

FIG. 3. Cycling of radionuclides through the marine biota.

Primary producers

The importance of phytoplankton in the cycling of radionuclides varies with space and time[3]. Not only do phytoplankton serve as food for filter-feeding animals while alive and in suspension, but after death they settle to the bottom where they either become food for detritus-feeders or decompose and return to the environment nutrient elements used in the synthesis of organic substances. Since phytoplankton have a large surface area per unit weight upon which adsorption occurs and since they absorb from the water a large number of elements essential for life, it can be assumed that they will be very instrumental in the removal of radionuclides from seawater. In our laboratory we have observed that in a very short time nearly all the radioactivity of a mixed-fission-product solution added to cultures of marine phytoplankton becomes associated with the cells.

All species of phytoplankton will not be equally important in the cycling of all radionuclides in the oceans, based on their capacity to concentrate the radionuclide. This has been shown in a comparison of the simultaneous accumulation of radioactive strontium and yttrium by twelve species of phytoplankton.[4] In Table 2 it can be seen that with the exception of *Carteria* and *Thoracomonas*, the algae tested concentrated radioactive yttrium to a much greater extent than radioactive strontium.

Table 2. Differential uptake of radioactive strontium and yttrium by algae[4]

Species	Activity from strontium (%)	Activity from yttrium (%)
Carteria sp.	100.0	—
Thoracomonas sp.	50.4	49.6
Amphora sp.	10.0	90.0
Navicula sp.	8.5	91.5
Chromulina sp.	8.2	91.8
Chlamydomonas sp.	6.5	93.5
Nitzschia closterium	6.0	94.0
Nannochloris atomus	5.7	94.3
Chlorella sp.	5.3	94.7
Porphyridium cruentum	4.4	95.6
Gymnodinium splendens	4.1	95.9
Gyrodinium sp.	2.3	97.7

For phytoplankton to be of importance in the passage of radionuclides up the food web it is not only necessary that the cells accumulate the radioactivity, but also that it be retained for considerable periods of time. This is of particular importance when there is only a single addition of radioactivity to seawater or in instances of acute pollution. With the passage of time phytoplankton continue to divide but the availability of the radioactivity to the cells continues to decrease. Each phytoplankton cell becomes less and less radioactive by continued division without further uptake of radioactivity. This is due to "biological dilution" or the reduction by cell division of radioactivity per unit weight of protoplasm. If conditions are suitable for rapid cell division, the radioactivity within the cell can be drastically diluted in a relatively short time; a 50 per cent reduction of activity per cell occurs with each division in the absence of radioactivity in the water.

The amount of phosphorous-32 exchanged by *Nitzschia* cells that were grown in medium containing phosphorous-32 varied with the concentration of phosphorous in the medium in which the cells were grown, the physiological condition of the cells, that is, whether they were phosphate-deficient or nondeficient, and the length of time the cells were grown in medium containing phosphorous-32.[5] Cells grown in the higher phosphorous concentration exchanged a larger percentage of phosphorus than cells grown in a lower concentration regardless of time in the medium or the physiological condition of the cells (Table 3). Phosphate-deficient cells kept for 20 hr in medium containing phosphorus-32 exchanged less phosphorus than nondeficient cells kept for 20 hr in a similar medium. Nondeficient cells kept for 7 days in medium containing phosphorus-32 exchanged a smaller percentage to the medium than nondeficient cells kept for 20 hr in the same type of medium.

Even though phytoplankton remove large amounts of radionuclides from seawater, the amount of radioactivity that can be passed up the food web will vary with size of cells, total number of cells in the water, and the concentration of the radionuclide in the cells. The size and number of particles present in the water are among the more important factors affecting the efficiency of the filtering mechanism of filter-feeding animals. Since both species (size) and numbers of cells fluctuate with space and time, the importance of phytoplankton in passing radioactivity up the food chain will vary in a similar manner. The effects of both size of cells and numbers of phytoplankton cells in the water upon the filtering rate of the hard clam, *Mercenaria mercenaria*, have been determined with cells labelled with radioactivity.[6]

Size of cells affects their rate of removal from water by the filtering activity of the hard clam (Fig. 4). The slopes of the curves showing the removal of the two smaller green forms, *Nannochloris* (2 μ in diameter) and *Chlorella* (4 μ in diameter), were similar. Also, the rates of removal of the two larger diatoms, *Nitzschia* sp. (19 $\mu \times 5\ \mu$, length and width) and *Nitzschia closterium* (43 $\mu \times 4\ \mu$, length and width), were in close agreement. However, many more diatoms were ingested by the clam

Table 3. *Exchange of phosphorus by* Nitzschia closterium *cells*[5]

Phosphorus in medium*	Length time cells in phosphorus-32 medium	Physiological condition of cells	Phosphorus exchanged (%)
45.5	20 hr	Nondeficient	30.6
	20 hr	Phosphate deficient	5.1
	7 days	Nondeficient	2.2
1,137.5	20 hr	Nondeficient	92.7
	20 hr	Phosphate deficient	25.4
	7 days	Nondeficient	17.3

* Microgram atoms of phosphate phosphorus per litre.

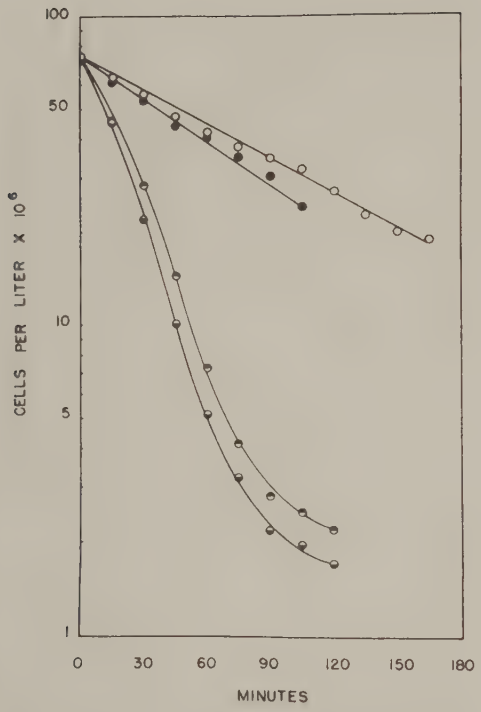

FIG. 4. Rates of removal of unicellular phytoplankton from suspension by filter-feeding activity of the hard clam.[6]

○ = *Nannochloris;*
● = *Chlorella;*
◓ = *Nitzschia* sp.;
and ◒ = *Nitzschia closterium.*

than green forms as shown by the much faster rate of removal of diatoms from the water. Even though the number of cells present in suspension was the same for the green algae and the diatoms, the diatoms represented a larger amount of protoplasm and would contain more radionuclides of those accumulated equally per unit weight of protoplasm by the different species.

The numbers of diatoms in suspension also have an effect upon the filtering rate of the hard clam (Fig. 5). There is much similarity between the curves representing the removal of cells at the two intermediate population sizes. The curves representing the highest and the lowest population sizes, while being somewhat similar, are quite different from the curves for the intermediate-size populations. Obviously, the number of *Nitzschia closterium* cells in the water does affect the rate at which the clam removes these diatoms, and this would control the amounts of radionuclides that could enter the clam associated with the diatoms. Also, the filtering rate of the oyster was found to be reduced when exposed to heavy suspensions of micro-organisms.[7]

Different species of phytoplankton that accumulate a radionuclide to the same level and are removed from the water with the same efficiency by a filter-feeding animal may not result in these animals becoming equally radioactive. This is due to all species of phytoplankton not being digested with the same efficiency. Thus, they cannot be equally important in the cycling of radionuclides in the ocean. If digestion and utilization of the ingested food occur, a positive correlation

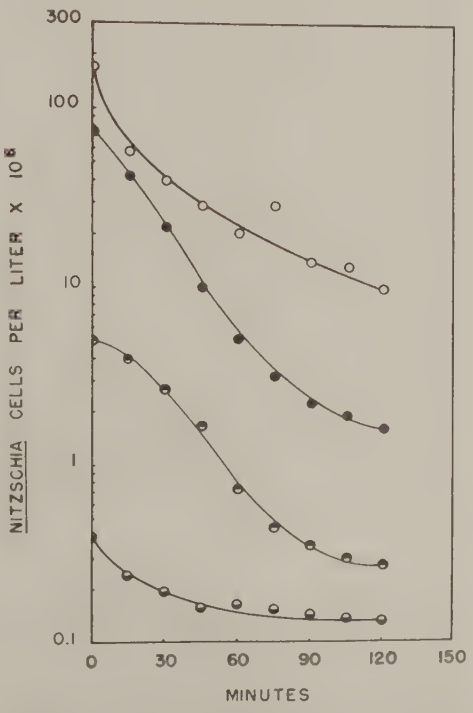

FIG. 5. Effect of number of *Nitzschia closterium* cells on their rate of removal by the hard clam.[6]

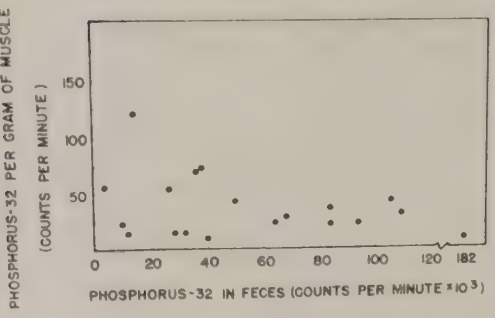

FIG. 6. Failure of oysters to utilize *Chlorella* cells as shown by the lack of correlation between phosphorus-32 in the adductor muscle and that passing through the digestive tract.[8]

will be obtained between the amount of food passing through the intestinal tract and the amount of nutrient material assimilated by the tissues of the animal. Conversely, the lack of correlation will suggest that no utilization of this ingested material occurs. Oysters were fed *Carteria*, *Skeletonema*, *Chlamydomonas* and *Chlorella* labeled with radioactive phosphorus.[8] A good correlation was found between the number of radioactive algal cells, and therefore the phosphorus-32 in the gut of the oyster, and the radioactive phosphorus of the adductor muscle when oysters fed on *Carteria*, *Skeletonema* and *Chlamydomonas* cells. However, there was no correlation when oysters fed on *Chlorella* (Fig. 6). Even though there were more radioactive *Chlorella* cells passing through the intestinal tract of some oysters, there was no additional accumulation of phosphorus-32 in the adductor muscle. Accumulation of phosphorus-32 was followed in the adductor muscle of the oyster since it was believed that phosphorus-32 could get into this tissue only from metabolic processes.

Consumers

The sequence of "eat and be eaten" is very complex in the marine environment, especially when one considers the variety of organisms eaten. Another complicating factor is that the food of animals changes at different periods in their life history. While it is difficult to follow food webs, a knowledge of them is necessary if the cycling of radionuclides through the biota is to be understood. Animal life in the oceans is dependent either directly or indirectly upon phytoplankton. For the most part, the larger marine animals and fishes are not able to feed on these small plants. These animals are dependent on other animals possessing filtering mechanisms enabling them to remove the minute plant cells from seawater. There are a vast number of small animals, as well as many larger animals such as oysters and other shellfish and even some fish, for instance menhaden, which feed directly on the phytoplankton. These, in turn, may serve as food for many of the larger animals. However some fish feed on smaller fish, and still others on bottom animals. These bottom-dwelling animals also are dependent on the phytoplankton, either while living or as organic particles following their death and settling to the bottom. Some bottom forms feed on other bottom-dwelling animals, but all are ultimately dependent on the phytoplankton of the upper water layers.

Primary consumers. It is now known that the accumulation of most radionuclides by an organism occurs at a faster rate from food than from water. Also, it has been assumed that regardless of whether the radionuclide is accumulated from food or water, activity in the organism eventually will reach the same level. Using the brine shrimp, *Artemia salina*, we have found[9] that zinc-65 not only is accumulated faster from food than from water, but that the animals will never accumulate as much zinc-65 from water as from food, since they do not live long enough (Fig. 7). Since *Artemia* live for 4–6 months under laboratory conditions it can be seen that the line representing the accumulation of zinc-65 from water, if extended to 6 months, would not reach as high a level as the line representing the accumulation of zinc-65 from food.

Filter-feeding animals have the capacity to concentrate different radionuclides even though they are living in the same environment.[10] For example, clams, *Mercenaria mercenaria;* oysters, *Crassostrea virginica;* and bay scallops, *Aequipecten irradians* living on muddy sand flats concentrated different radionuclides as a result of their filtering activities (Table 4).

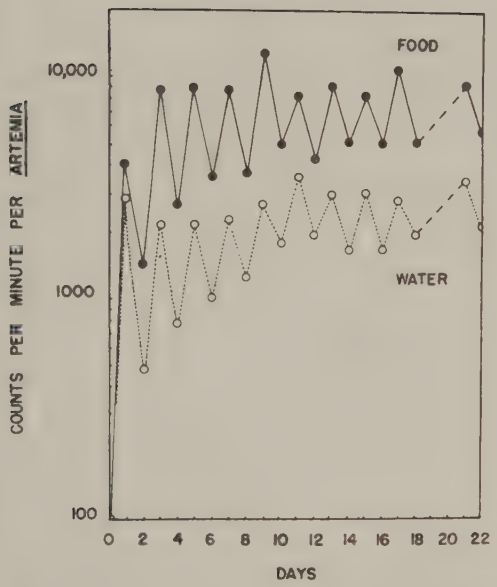

FIG. 7. Comparison of accumulation of zinc-65 by *Artemia* from food and water.[9]

Data on organisms that are reservoirs for specific radionuclides are very important in planning a sampling program to investigate suspected instances of radioactive pollution. Such data allow one to sample a particular organism that is a biological indicator for radioactivity to determine whether or not pollution is present. It is also important to know the distribution of the radionuclide in the organism.

For instance even though scallops might contain large amounts of manganese-54, most of this activity is present in the kidney, a portion of the scallop that is not eaten by man, and relatively little is present in the adductor muscle, the part that is consumed by man.

Secondary consumers. Fish participate in three different ways in the cycling of radionuclides in an estuary. Those used as seafood are the final link in the food web which can pass radioactivity to man. They also can pass radioactivity to other fish feeding upon them. Finally, if not eaten by man or other predators, they die and their bodies decompose, releasing radioactivity back into the environment to start the cycle again.

The extent to which fish can concentrate radionuclides depends not only upon the availability of the radionuclide, but also upon the physical state of the isotope in seawater, and the metabolic requirements of fish for it. Some radionuclides are particulate in solution and are not readily absorbed through living membranes.[11] For example, cerium-144-praseodymium-144 ingested by the croaker, *Micropogon undulatus*, is almost entirely excreted after 24 hr, while less than 1 per cent is assimilated (Table 5). Cycling of particulate radionuclides thus may be short-circuited from the food chain back to the water or sediments.

Table 5. Assimilation and excretion of cerium-144-praseodymium-144 by croaker, Micropogon undulatus. *Means of four fish per sample*[11]

	Per cent of dose after 18 hr	24 hr
Assimilated	0.5	0.3
Excreted	76.9	99.0
Present in digestive tract	22.6	0.7

Table 4. Radionuclides and their relative abundance in four species of molluscs[10]

	^{144}Ce	^{106}Ru	^{137}Cs	^{95}Zr^{95}Nb	^{54}Mn	^{65}Zn	^{40}K
Scallops	4	3	2	*	1†	5	‡
Oysters	2	3	‡	§	§	1†	‡
Clams	1†	2†	‡	§	§	§	‡
Mussels	1†	2†	§	§	§	‡	‡

* Evident after subtraction of ^{54}Mn spectrum.
† Indicator isotope.
‡ Present but not relatively abundant
§ Indication of presence.

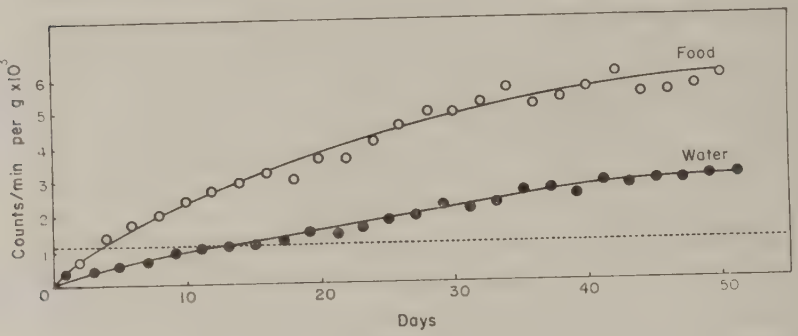

FIG. 8. Accumulation of zinc-65 from food and water. Dotted lines indicate cpm/g in food and water.[12]

Fish accumulate radionuclides from water and from their food. The uptake of zinc-65 by flounder from food has been compared to its uptake from water for a period of 44 days.[12] Accumulation of zinc-65 continued throughout the experiment whether the source of activity was food or water (Fig. 8). Fish obtaining zinc-65 from food concentrated it to a higher level than fish obtaining zinc-65 from water. When the zinc-65 of the fish in active water was expressed as a concentration factor, it was found that an apparent equilibrium with the water was reached after 20 days.

The role of the biota in the cycling of radionuclides is influenced by retention as well as by accumulation rates and concentration levels. Retention may be expressed as turnover time or biological half-life, the latter being the time required for an organism to eliminate one-half of a given substance from its body. Of course, physical decay reduces the amount of the particular radionuclide tending to gradually remove it from circulation. The combined processes of biological turnover and physical decay are expressed as the effective half-life, which should be the criteria applied when evaluating the possible hazard from seafood rather than either individual process. The effective half-life of a radionuclide varies not only among different radionuclides but also among species, and it is influenced by temperature, food and other ecological factors. Retention curves are often composed of two or more components indicating different turnover rates. For example, the retention of niobium-95 by croaker is expressed as a two-component curve having biological half-lives of 5 days and 465 days.[11] However, due to the influence of physical decay (half-life of 35 days), the effective half-lives of the two components were 3.7 days and 33.1 days. This means that one component (representing 51 per cent of the initial niobium-95) was being returned to the water at a 3.7-day half-life rate, and the other (49 per cent of the initial niobium-95) at a 33.1-day half-life rate. This particular radionuclide therefore would be distributed over a large area as the fish swims from place to place.

EXPERIMENTAL COMMUNITY STUDIES

Rates of accumulation of radionuclides and levels reached by marine organisms have been determined in laboratory experiments using single species of organisms in relatively small volumes of water. However, if the cycling of radionuclides through the marine environment is to be better understood, experiments also must be conducted in relatively large volumes of water, such as ponds, containing communities of organisms. At our laboratory observations have been made on the movement of zinc-65 in an experimental salt-water pond containing a community of estuarine organisms.

Zinc-65 introduced into the pond moved quickly from the water to the sediment and biota. After 17 hr, 66 per cent of the original radioactivity had been lost from the water. After 10 days, 97 per cent of the isotope had disappeared from the water. The biota in the pond included several types of organisms such as oysters, clams and fish (croaker) that are

used as seafood by man. Of these organisms, oysters accumulated more of the radionuclide more rapidly than did other organisms. After 100 days the meat of each oyster contained 0.9 μc of zinc-65 (10 mc of zinc-65 was added to 45,000 l. of seawater in the pond).

The organism which concentrates a radionuclide to the highest degree is not necessarily the controlling factor in determining desirable levels of radioactivity in an estuary. Rather, the organism which concentrates the radionuclide to the highest degree in relation to the amount eaten by man will be more important. However, in the pond experiment, the oyster concentrated more zinc-65 than the other organisms and it was also the most desirable seafood organism tested.

DISCUSSION

Seafood organisms that contain radioactivity are a potential health hazard to man. The extent of this hazard depends upon the amount of radioactivity concentrated in the edible tissues of the organisms. Since the amount of radioactivity concentrated by the organisms depends in part on the amount of radioactivity in the water, it is necessary to have acceptable levels of radioactive elements in seawater as well as in seafood organisms. An important criteria for establishing these levels is the specific activity or ratio of the quantity of radionuclide to total element in the water and organisms.

The importance of the specific activity in seawater in relation to the transfer of radionuclides from seafood organisms to man is discussed in *National Academy of Science—National Research Council Publication* 985[13] as follows: "If the specific activities of the elements of the sea in the region of growth, development, and habitation of marine food organisms can be maintained below the allowable specific activities of these elements in man and his seafood, the allowable radiation for any individual cannot be exceeded as a result of the consumption of marine products." That most marine organisms readily concentrate radionuclides does not invalidate this statement because an organism that concentrates a radionuclide also concentrates the stable element. Thus, the specific activity of the material taken from the environment will not be altered by the organisms. Similarly, man cannot change the specific activity of material assimilated from seafood.

Fish and shellfish are the marine animals of greatest concern from the standpoint of public health. In evaluating the health hazard and determining which organism will be the source of the largest amounts of radioactivity, it is necessary to know what radionuclides are entering the marine environment. Also, since all radioactive elements are not equally harmful, it will be necessary to know the amount of each radionuclide present in the water in which the animals lived and the duration of the pollution. If the isotopes are present for only a short period of time, organisms which have high metabolic rates, large surface areas, or mechanisms for rapidly removing the radioactive materials from the water may be the most radioactive after a few hours. Organisms which have slower rates of accumulation but which have higher concentrating capacities could be as radioactive if given sufficient time to achieve uptake.

It is important to determine the accumulation of the different radionuclides by the various marine organisms in order to identify those that can serve as "biological indicators." Biological indicators are defined as those organisms concentrating relatively large amounts of specific radionuclides making it possible to detect the presence of these isotopes in the environment through an analysis of the organisms. Biological indicators are the only practical method of detecting radioactivity present in the environment in very low concentrations. For example, several species of seaweed that entered one of our experimental ponds which had previously contained zinc-65 concentrated this isotope even though there was no detectable activity in the water of the pond. Oysters, *Crassostrea virginica*, held in this pond rapidly concentrated zinc-65 many times over its initial concentration in the water. Thus, these organisms can serve as biological indicators for zinc-65 in seawater.

Acknowledgments—The author thanks JOHN P. BAPTIST, THOMAS W. DUKE, CLAIRE L. SCHELSKE and RICHARD B. WILLIAMS of the Radiobiological Laboratory, Beaufort, N.C., for their assistance in the preparation of this paper.

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REPRINTED FROM

The Proceedings of the Second International Water Pollution Research Conference, Tokyo 1964

PERGAMON PRESS 1965

NEW YORK - OXFORD - EDINBURGH - PARIS - FRANKFURT

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Reprint from the 2nd International Conference on Water Pollution Research 1964

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INTRODUCTION

Considerable laboratory data have been published on the uptake, accumulation, and loss of individual radionuclides by marine organisms, but very few on a mixture of radionuclides such as are produced by the fission of uranium-235. This lack of information is probably due to the difficulty of working effectively with such mixtures. These mixtures not only change in composition with time, but selective uptake in tissues of marine organisms produces different mixtures of radionuclides, which also change with time. On the other hand, the uptake of mixtures of radionuclides released into the oceans from nuclear detonations has been studied, for example, by radiological surveys such as Operation Troll[1] and those conducted by the Laboratory of Radiation Biology of the University of Washington.[2] However, data collected in the marine environment may be complicated by interacting factors and uncontrollable variables, making it difficult to accurately evaluate the observed phenomena.

The problems in need of solution are concerned with the simultaneous uptake of several radionuclides since mixtures, rather than individual isotopes, are released into the environment. Two or more radionuclides have been used to some extent in experiments on foods and feeding, and in ecological and accumulation studies. Two radionuclides, calcium-45 and phosphorus-32, have been used to label two species of phytoplankton in order to simultaneously follow their rates of removal from sea water by clams, *Mercenaria mercenaria*.[3] The cycling of both zinc-65 and chromium-51 was followed through a community ecosystem of organisms in a salt water pond (Unpublished data of Radiobiological Laboratory staff). Accumulation studies with a 2 month old mixture of fission products revealed that the clam, *Tapes semidecussata*, quickly concentrated certain radionuclides.[4]

The purpose of the investigation reported here was (1) to follow the decay characteristics and to identify the strongest β- emitters of two mixtures of fission products, (2) to measure the rate of particle formation of fission products in sea water, (3) to delineate the ecological role of phytoplankton in the cycling of fission products in a marine environment, (4) to determine the amounts of β- activity accumulated by marine animals, from different trophic levels, used as seafood by man, (5) to compare the ratio of the β- to the γ- activity simultaneously accumulated by these animals, and (6) to identify the tissues of these animals containing the highest concentrations of radioactivity.

The Radiobiological Laboratory is jointly supported by the Bureau of Commercial Fisheries and the Atomic Energy Commission.

NATURE OF THE FISSION PRODUCT MIXTURES

It is obvious that mixtures of fission products contain many radioisotopes which decay at different rates and emit different types of particles or rays which vary markedly in their energy. A number of these isotopes have parent–daughter relationships which, when disturbed, proceed to radiological equilibrium in different patterns and at different rates.

The fission products used in the present investigation consisted of two separate mixtures. These mixtures were separated from heavy metals which had been exposed for 40–60 days in the reactor at the Oak Ridge National Laboratory and were shipped within 45 days after removal from the reactor. Each mixture is identified by number and age in days. For example, "MFP-2-35" denotes that mixture number two was used 35 days after the date of shipment from Oak Ridge.

Differences of the isotopic content of these two mixtures is apparent from comparison of their rates of loss of gross β- activity expressed as disintegrations per

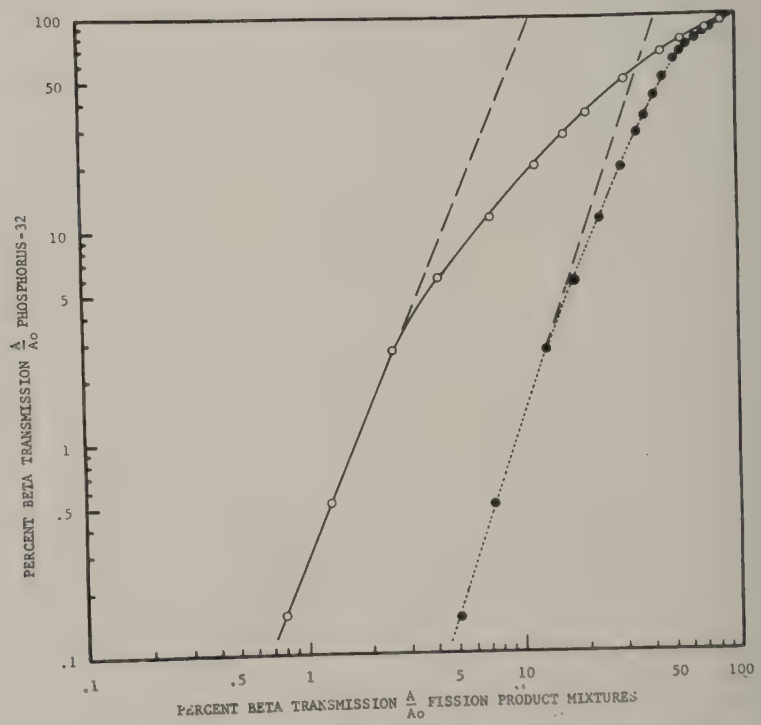

Fig. 1. Comparison of relative transmission through several absorber thicknesses of beta radioactivity of two mixtures of fission products with that of a standard P^{32}. After determining the slope of the straight portion of each curve, the maximum energy was estimated from a slope-energy curve to be that of Pr^{144} in both mixtures. Dots represent a mixture of fission products 302 days old (MFP-1) and circles a mixture 28 days old (MFP-2).

second (d.p.s.) (TABLE 1). This was evident also when rates of loss of γ- activity were compared. The second mixture apparently had a shorter storage period before shipment since more of the β- activity was composed of isotopes of short half-life.

TABLE 1. DIFFERENCES IN DECAY RATES OF β- ACTIVITY OF TWO MIXTURES OF FISSION PRODUCTS, INDICATING DIFFERENCES IN EITHER THE RADIOISOTOPES PRESENT OR THEIR CONCENTRATIONS

Mixture 1 (MFP-1)		Mixture 2 (MFP-2)	
Days after shipment	Gross β activity (d.p.s./λ)	Days after shipment	Gross β activity (d.p.s./λ)
0	191,660	0	196,000
156	19,038	155	13,683
200	15,405	198	10,054
245	11,841	246	7559
273	10,403	275	6586

Individual radioisotopes were identified in a few samples by determining the transmission of β- activity through aluminum absorbers after the method of HARLEY and HALLDEN.[5] The relative transmission of activity of a standard through several absorber thicknesses was plotted against the relative transmission of the unknown on logarithmic paper. The slope of the resulting line was determined and the maximum energy estimated from a slope-energy curve. Using this method, aluminum absorption curves were obtained for two mixtures, one at age 28 days (MFP-2) and the other at age 302 days (MFP-1) (FIG. 1). In both mixtures the most energetic emitter determined from the slope of the line was praseodymium-144. By extrapolation of these lines, this isotope was found to account for 11·5 per cent of the β- activity of MFP-2-28 and 44 per cent of MFP-1-302.

CHEMICAL AND PHYSICAL STATE OF FISSION PRODUCT MIXTURES IN SEA WATER

In the laboratory, the uptake of fission products by marine organisms is dependent upon the conditions under which the tests are conducted. The chemical and physical state of elements in sea water may be altered during formation of insoluble particles. Many of these particles settle out of sea water or adhere to surfaces, increasing or decreasing the availability of individual radioisotopes to plankton and larger organisms.

The rate of formation of particles in sea water was followed by filtering portions of sea water at various times after the addition of MFP-2-37. During the first 5 days, the amount of radioactivity retained on the Millipore filters (Type HA, pore size 0·45 μ) increased, indicating either that more radioactivity was becoming associated with particles already present or that more particles were being formed on which the radioactivity could be adsorbed (TABLE 2). After this time there did not appear to be any further increase in the amount of radioactivity retained on the filter.

Table 2. Increased retention of β- activity on Millipore filters with time after the addition of MFP-2-37 to sea water

Time after addition of MFP-2 to sea water (days)	Radioactivity retained on filter (%)
0	8·8
1	18·7
2	37·6
5	64·1
9	60·0

When mixtures of fission products were added to sea water there was an appreciable loss of radioactivity from the water as a result of particles settling and carrying the adsorbed radioactivity with them. In sea water filtered prior to the addition of MFP, the decrease in radioactivity due to particles settling was less than in unfiltered water. Changes occurring in the β- activity, after addition of MFP-1-248 to 2 volumes of sea water, one filtered with a Millipore filter and the other with cotton were followed in one of the tests (Table 3). Removal of the larger particles by filtering the sea water through cotton was less efficient in preventing the loss of radioactivity from sea water than a more complete removal of suspended materials by the use of a

Table 3. Reduction of β- activity due to particles settling out of sea water, filtered prior to the addition of MFP-1-248

Time after addition of MFP-1 to sea water (days)	Per cent of radioactivity lost through settling	
	Millipore filtered	Cotton filtered
1	5·6	14·2
2	8·5	34·5
4	16·5	43·5
7	22·7	44·6
15	29·4	47·3
22	37·2	61·7

Millipore filter. Agitation of the flasks increased the radioactivity of the aliquots of sea water, demonstrating that losses from the water resulted from particles settling. It is likely that the greatest loss of radioactivity in the sea water was from the adsorption of radioisotopes to particles which settled out. A second cause of loss was hydration and precipitation with subsequent settling of these particles. Therefore the importance of suspended particles, such as plankton, in the sea in accumulating radioactivity is apparent.

UPTAKE OF MIXED FISSION PRODUCTS

The uptake of fission products by phytoplankton, *Nitzschia closterium* and *Carteria* sp.; oysters, *Crassostrea virginica;* bay scallops, *Aequipecten irradians;* shrimp, *Penaeus setiferus;* and fish, *Micropogon undulatus*, was measured. Uptake of radio-

nuclides by all organisms except oysters was from sea water: oysters were fed radioactive *Carteria* cells grown for 5 days prior to feeding in sea water containing a mixture of fission products. The temperature of the sea water used in all experiments ranged from 19·8° to 25·9°C and the salinity from 30·1 to 36·4‰. The sea water in which the animals were kept was changed every three days.

Methods of collecting and preparing biological material for measurement of radioactivity content varied with the particular organism. For β- determinations, phytoplankton cells were collected from sea water on a Millipore filter. For γ-measurements, the cells and filter were dissolved in nitric acid and diluted to 2 ml volumes. Before making radioactivity measurements of the other organisms, certain tissues were removed by dissection and ashed by a combination of digestion with nitric acid and a 5 min exposure in a muffle furnace at 600°C. The ash was then dissolved in nitric acid and made up to 10 ml volumes. For β- radioactivity measurements, 5 ml aliquots were pipetted into plastic dishes and dried under an infrared lamp. Two milliliter aliquots were pipetted into screw-cap vials for γ- determinations.

Both β- and γ- activity measurements were made on sea water and biological materials. β- Measurements were made with a shielded end-window Geiger-Muller detector and scaler, calibrated with a thallium-204 standard, since this was an approximate average of the energy levels of the biologically important radioisotopes. A scintillation well-type sodium iodide crystal detector and scaler calibrated with barium-137 of a cesium-137–barium-137 standard was used for γ- activity measurements. Both standards were obtained from the National Bureau of Standards. Radioactivity measurements are expressed as d.p.s./g to facilitate their conversion to microcuries.

Phytoplankton

The accumulation of fission products by non-dividing *Nitzschia closterium* cells kept in the dark was measured. At the density of the culture used, 11×10^7 cells/l. 32·6 per cent of the total β- activity was removed during the first 15 min from sea water containing MFP-2-80. After 48 hr, 60·1 per cent of the activity was associated with the cells. This is an indication that much of the β- activity occurring in a fission product mixture becomes associated with phytoplankton cells as a result of non-metabolic activity, probably due to adsorption and exchange.

Carteria cells were grown in sea water containing MFP-1-179. These cells accumulated radioactivity from the medium throughout the observed growth period of 144 hr. The per cent transmission of the β- activity of the cells at different absorber thicknesses was greater than that of the sea water from which the cells had been removed, indicating, possibly, a greater percentage removal of cerium-144 praseodymium-144 than of other radioisotopes of weaker energies.

The decay rates of the β- activity of these cells and the activity in an aliquot of sea water removed prior to adding the *Carteria* cells were followed over a period of 42 days. The per cent of activity remaining after certain periods of time was measured (Table 4). Apparently the more rapid decay rate of the activity of the cells removed after short periods of time in water containing the fission product mixture indicates a rapid uptake of isotopes of short half-life, with the uptake of the isotopes with longer half-lives proceeding more slowly. The important point is that cells remaining

for 144 hr in the sea water containing the mixture had a loss of activity most like that of the sea water. This is an indication that it required approximately 144 hr for the population of cells to take up enough of the different radioisotopes so that their decay rate was about equal to that of the mixture of radioisotopes initially in the sea water.

The loss of β- activity from *Carteria* grown for 8 days in sea water containing MFP-1-227 was followed. Only small amounts of activity were lost from the cells to sea water and to distilled water. This loss ranged from 3 to 15 per cent, depending on whether the temperature of the water was 22° or 100° C. The largest losses occurred at the higher temperature. However, when ethylenediamine-tetraacetic acid (EDTA), a chelating material, was added to the sea water used in washing, about 73 per cent of the radioactivity of the cells was lost. These results indicate that radioactivity

Table 4. Decay of β- activity associated with *Carteria* cells removed at different times from sea water containing MFP-1-179. Also shown is the decay of activity in an aliquot of sea water removed prior to adding the *Carteria* cells[1]

Time cells remained in sea water (hr)	Percent of original radioactivity remaining at days indicated						Per cent of radioactivity lost in 42 days
	7	14	21	28	35	42	
0·25	74·4	66·8	66·1	62·7	60·4	57·4	42·6
0·50	86·7	67·4	66·2	62·8	60·5	56·2	43·8
1	87·7	78·3	76·1	73·1	72·2	66·6	33·4
2	87·4	80·7	78·2	77·0	73·0	69·5	30·5
6	88·7	70·6	68·2	74·6	73·6	66·5	33·5
24	84·6	87·9	84·2	72·8	70·8	67·9	32·1
48	91·5	84·0	82·4	79·8	77·4	74·3	25·7
72	98·2	86·3	83·6	80·6	76·3	73·9	26·1
144	94·5	90·6	83·2	84·3	80·0	76·5	23·5
Sea water	—	92·3	89·1	—	82·9	78·8	21·2

accumulated by phytoplankton in the natural environment would not be lost readily.

The radioisotopes accumulated by *Carteria* cells from sea water containing MFP-2-82 were identified by measuring their energy after they had been separated from each other by ion exchange. After growing for 8 days in sea water, *Carteria* cells were removed from the water by centrifuging, washed with double distilled water, and ashed, first on a hot plate with concentrated nitric acid and then in a muffle furnace at 600 C. The ash was dissolved in a few drops of 7 N hydrochloric acid and adsorbed onto a column of Dowex-50 cation exchange resin in the hydrogen form. Anionic complexes were removed from the column with 0·1 N hydrochloric acid, tetravalent ions with 0·05 M oxalic acid, trivalent ions with 5 per cent citric acid pH 3, and both divalent and monovalent ions with 5 per cent citric acid pH 5.

β-Absorption tests on the solution containing the anionic complexes indicated that the strongest energy isotope present was rhodium-106 of the ruthenium-106–rhodium-106 parent daughter. The isotopes of the tetravalent group contributing to the radioactivity of the cells were very weak and included zirconium-95–niobium-95. Cerium-144–praseodymium-144 contributed a large part of the radioactivity of the

trivalent fraction. A slightly smaller quantity of radioactivity in this fraction was due to yttrium-91. The divalent–monovalent solution was found to contain β-energies which indicated the presence of strontium-90 and strontium-89.

Oysters

The uptake of β- and γ- activity by oysters fed *Carteria* cells containing MFP-2-35 was measured during a 16 day period. Cells from a 1 l. culture were added by an automatic delivery tube during an 8 hr period each bay to 120 l. of sea water containing 50 oysters. Each radioactivity measurement represents an average of 5 oysters. Radioactivity was accumulated rapidly by oysters for the first 2 days, but more slowly during the remainder of the experiment (FIG. 2). γ- Activity reached a

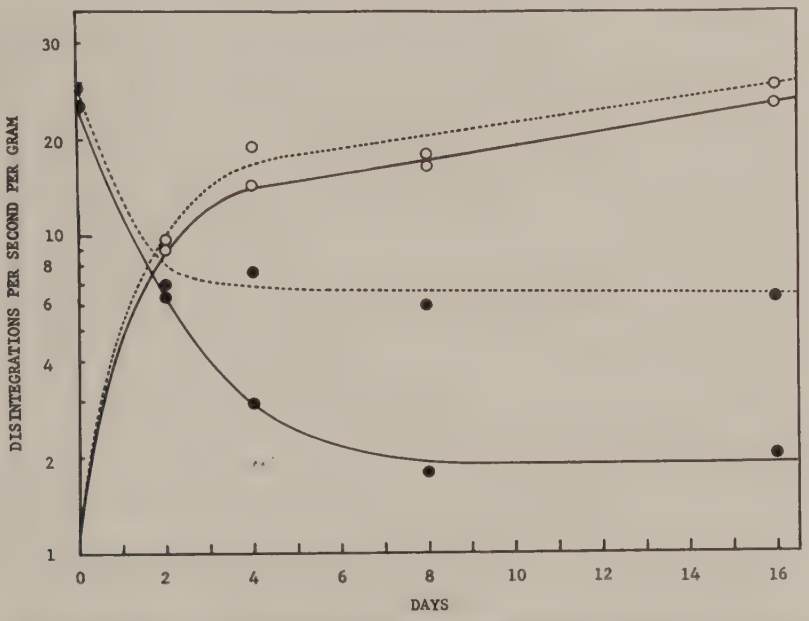

FIG. 2. Uptake and loss of radioactivity by soft tissues of oysters fed *Carteria* cells containing MFP-2-35. Broken lines represent γ- radioactivity; unbroken, β. Circles represent uptake, dots loss.

slightly higher concentration than β, resulting in a β- to γ- ratio similar to that in the *Carteria* cells. Of the total radioactivity available to the oysters, approximately 0·3 per cent was accumulated in the soft tissues.

The rate of loss of radioactivity from oysters was obtained by placing oysters remaining from the above experiment in flowing sea water. Approximately 76 per cent of both β- and γ- activity was lost within 2 days (FIG. 2). However, at the end of 8 days, 93 per cent of the β- activity had been lost, while γ- activity remained unchanged. After the eighth day there was no significant loss of either β- or γ-

activity. The initial rapid loss of 76 per cent was attributed to elimination of non-assimilated radioactivity from the gastrointestinal tract.

Scallops

The uptake of β- and γ- activity by the bay scallop from sea water containing MFP-2-482 was measured. The experiment was started with 60 scallops in 120 l. of sea water. Each radioactivity measurement represents an average of 10 scallops.

More β- than γ- activity was accumulated by the visceral mass, shell, and muscle of the scallop (Fig. 3). The visceral mass had the highest β- concentration, followed

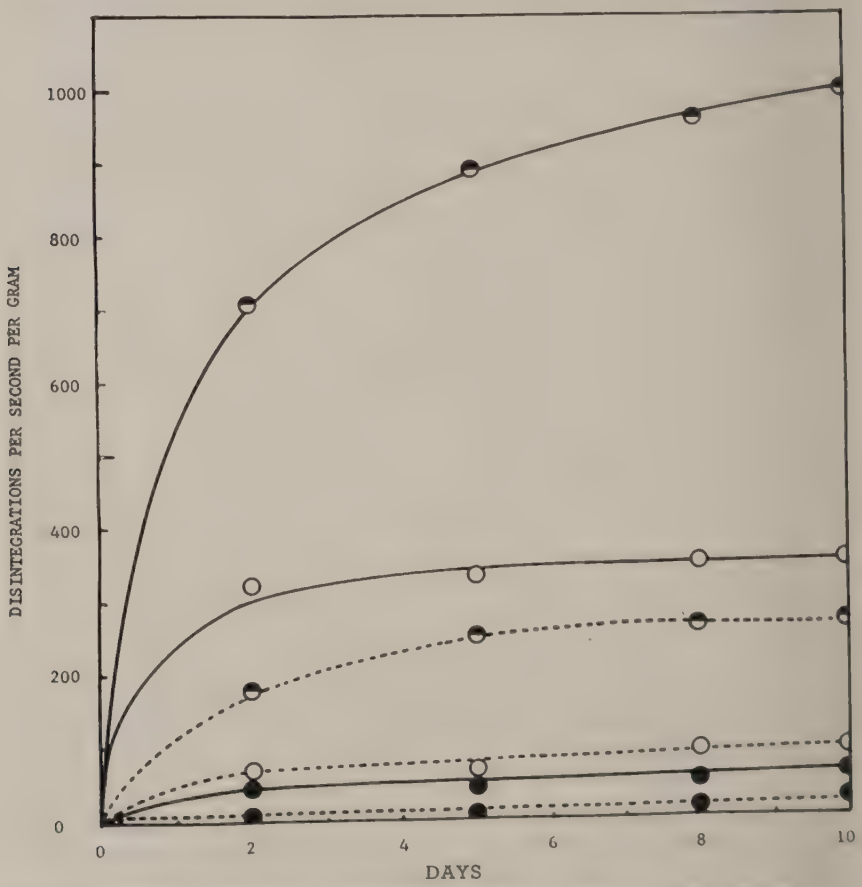

Fig. 3. Uptake of radioactivity by scallops from sea water containing MFP-2-482. Broken lines represent γ- radioactivity; unbroken, β. Circles represent shell; half-circles, visceral mass; and dots, muscle.

closely by the shell, while the muscle took up considerably less β- activity. γ-

Activity was accumulated in the same order as the beta activity but with smaller differences among the three tissues. Shell liquor, which contains a considerable quantity of sea water, had the same amount of radioactivity as the sea water.

The β- to γ- activity ratios and concentration factors of the tissues of scallops were calculated. It was found that the ratio in sea water was 8·5: 1; viscal mass, 11·5: 1; shell, 10·8: 1; and muscle 4·8: 1. From these ratios it can be seen that the visceral mass contained the greatest quantity of β- activity per unit quantity of γ- activity and muscle the least. Also, concentration factors were calculated for both beta and gamma activity in the tissues of the scallop. The β- concentration factor for visceral mass was 35, shell 29, and muscle 11. The γ- concentration factor for visceral mass 26, shell 23, and muscle 20. Muscle was the only tissue having a higher concentration factor for γ than for β.

Shrimp

The uptake of β- and γ- radioactivity by shrimp from sea water containing MFP-2-238 was measured for a 10 day period. Fifty shrimp were held in 120 l. of sea water. Each radioactivity measurement represents the average of 10 shrimp.

Uptake of radioactivity by shrimp was most rapid during the first 2 days (Fig. 4).

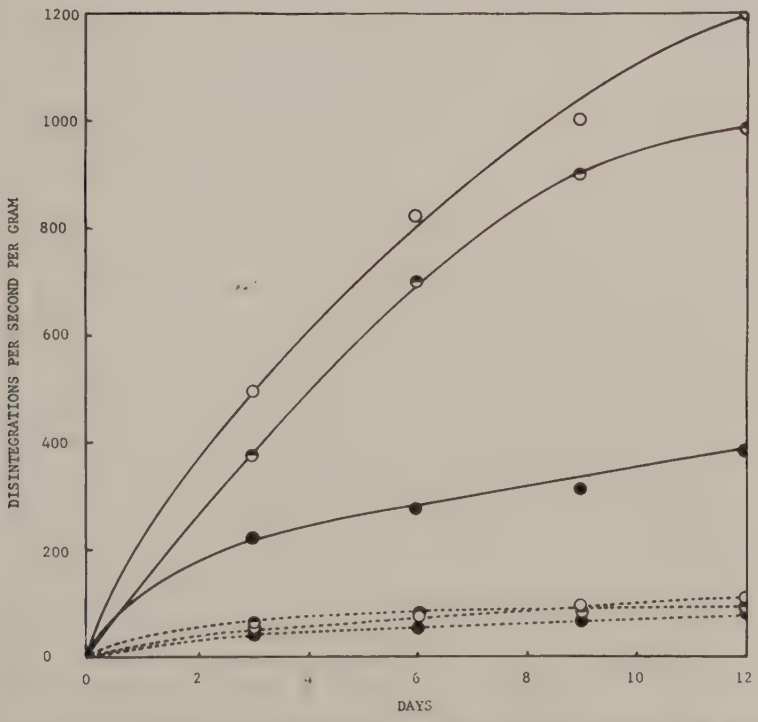

Fig. 4. Uptake of radioactivity by shrimp from sea water containing MFP-2-238. Broken lines represent γ- radioactivity; unbroken, β. Half-circles represent carapace; circles, head and viscera; and dots, muscle.

The β- radioactivity in the shrimp tissues ranged from slightly more than 1·4 times that of the γ- activity at the end of the experiment. As in the scallop experiment, the β- to γ- ratios of the radioactivity in the tissues were different from that of the sea water. The β- to γ- ratio for head and viscera was 3·6: 1; muscle 2·3: 1; shell 3·7: 1; and sea water 7: 1. When the β- activity of the tissues was compared to that of the

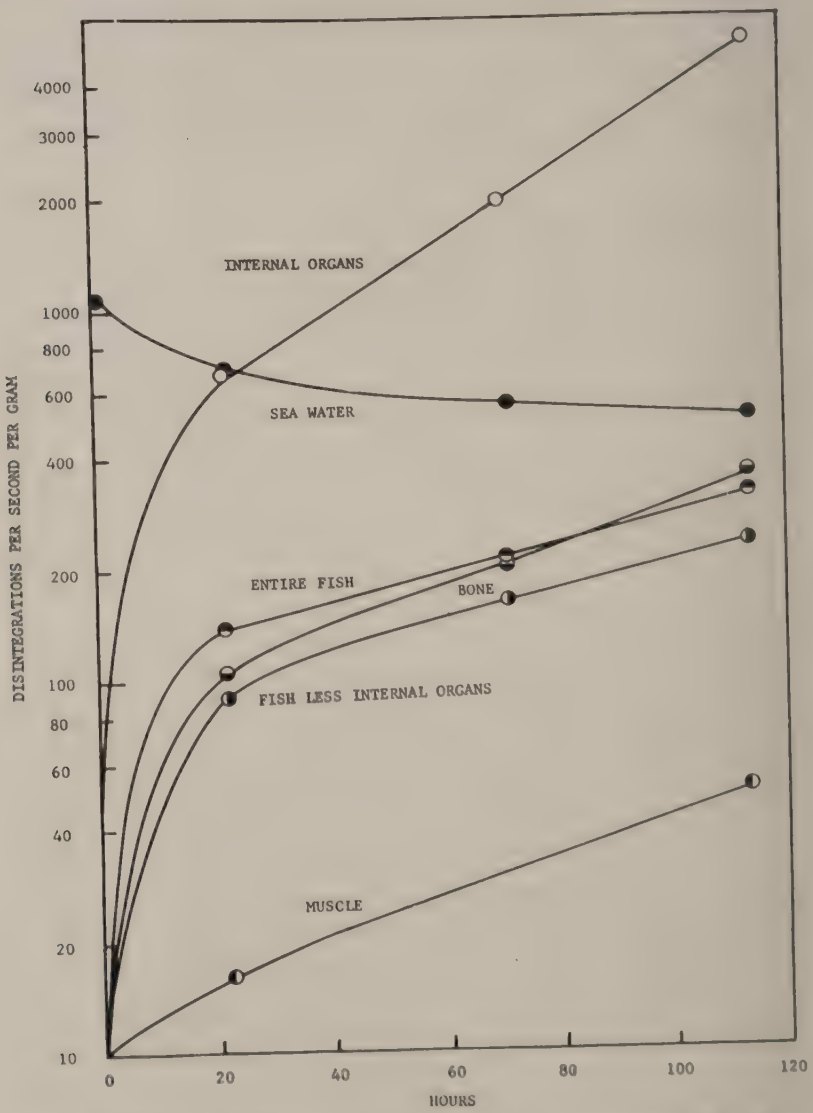

Fig. 5. Uptake of β- radioactivity by croakers from sea water containing MEP-1-186.

water the concentration factor for head and viscera was 3·5; muscle 0·6; and shell 10·2. The γ- concentration factor for head and viscera was 6·7; muscle 1·8; and shell 19·4.

Fish

The accumulation and tissue distribution of β- radioactivity by croakers from sea water containing MFP-1-186 were measured. Nine fish were held in 50.1 of sea water. Each radioactivity measurement represents the average of three fish. Also, identification of some β- emitters present in internal organs and bone samples was made by aluminum absorption analysis.

Accumulation of radioactivity by croakers was rapid during the first 20 hr, but thereafter continued at a reduced rate (FIG. 5). Concentration of fission products was highest in the internal organs, being approximately five times the initial amount in sea water. The curve representing the accumulation of activity by the bone was similar to the curve representing accumulation by the entire fish. Muscle accumulated the least amount of radioactivity. Even though the mass of internal organs represented a small fraction of the total weight of the fish, the curves representing activity of the entire fish with and without these organs are noticeably different.

Aluminum absorption analyses of β- activity indicated that internal organs contained an emitter with an energy corresponding to that of praseodymium-144 and accounted for approximately 26 per cent of the activity. Bone was found to contain an emitter with an energy corresponding with that of yttrium-90. This would also indicate that the parent strontium-90 was present. The proportion of total activity in the bone due to yttrium-90 was 37 per cent indicating that 74 per cent was due to strontium-90–yttrium-90 if these two isotopes were in equilibrium.

DISCUSSION

The greatest concern of those who oppose the disposal of radioactive waste or the release of radioactive materials from nuclear reactors into the oceans is the possibility of its return to man in seafood. However, to evaluate this possibility one must understand that factors are in operation in the oceans which dilute and disperse radioactive materials, while simultaneously other conditions tend to concentrate these substances. Radioactive materials introduced into the marine environment can either remain in solution, precipitate and eventually settle on the bottom, or be accumulated by plants and animals. Possibly the most important factor which accounts for a portion of the fission product materials remaining in solution in sea water is the large quantities of dissolved elements in the water. The soluble portion of radioisotopes is diluted in sea water with the stable element, making the radioisotopes biologically no more available to the biota than the stable element. Since many elements are present in excess of their biological need by organisms, this results in less radioactivity being accumulated by the biota than if there were smaller quantities of dissolved elements in the water. Also, the biota accumulate less radioactivity because sediments, whether in suspension or on the bottom, compete not only for the soluble protion but, in addition, for that portion which occurs as particles.

The capacity of unicellular algae to rapidly accumulate fission products from sea

water makes them very effective in the passage of radioisotopes to higher trophic levels.[7] In the present experiments, it was found that most, if not all, of the radioisotopes in the mixtures of fission products tested, became associated with the cells of the species of algae used. Thus, algae can accumulate radioisotopes whether they occur in the soluble or particulate state. If the isotope cannot be metabolized by the cells, it may be adsorbed to their surfaces.[8] The levels to which different radioisotopes are concentrated vary from species to species, and even parent daughter isotopes in equilibrium have been shown to be accumulated differentially.[9]

The extent to which seafood organisms are hazardous to man depends upon the the amount of radioactivity concentrated in the edible tissues. While radioactive particles cannot easily pass through the living membranes of larger organisms, they can be accumulated in the digestive tract of filter-feeding animals. If the filter-feeding animal is an oyster, particulate radioisotopes in the digestive tract will be passed on to man just as readily as soluble radioisotopes contained in the tissues, since all of the soft tissues of the oyster are eaten. Even undigested radioactive algae in the digestive tract of the oyster would be a source of activity to man. The concentration of fission products in the muscle tissue, presumably isotopes in the soluble state, was found to be relatively low in scallops, shrimp, and fish which are eaten by man. The adductor muscle of the scallop had a β- concentration factor of 11 and a γ-concentration factor of 20. The β- concentration factor of the muscle of the shrimp was 10·2 and γ only 1·8, while the muscle of fish had a β- concentration factor of less than 1. It should be noted that tissues such as bone are sometimes consumed when, for example, processed fish such as sardines and salmon are eaten. Even fission products in the entire body of "trash fish" may reach man indirectly through fish meal which is used as food for farm animals. While considerable information is available on the potential passage of radioactivity to man from marine animals, additional data are needed before the complete ecological implications can be known.

Additional research on the accumulation of radioactivity by marine organisms from mixtures of fission products is being planned by the staff of the Radiobiological Laboratory. To assist in these studies, a multi-channel analyzer operated with solid state detectors for β- and γ- measurements will be used. In addition to laboratory experiments, the accumulation of fission products by communities of marine organisms will be followed in large tanks and ponds. These pilot-model experiments will serve as a means of testing questionable findings from laboratory experiments. Also, in these experiments the competition among organisms for these materials can be observed, and the pathways in the food web taken by a particular radioisotope can be identified.

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FORMAL DISCUSSIONS

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The purpose of laboratory experiments on radionuclide accumulation or "uptake" by aquatic organisms enables one to understand and predict the behavior or "fate" of waste radionuclides released into an aquatic ecosystem. Generally speaking, an aquatic ecosystem is a complex association of water, sediments, plants and animals which interact to produce an exchange of materials.

The experimentalist usually simplifies matters by investigating one or two of the components of the ecosystem, for example water and fish, and one of the radionuclides and then measuring the accumulation of the radionuclide in the fish. It must be admitted that such an experimental arrangement is a poor approximation of an ecosystem contaminated by radioactive wastes.

Rice *et al.* have attempted to overcome some of the deficiencies of such experiments by using a mixture of fission products, rather than a single radionuclide, and then following the accumulation of radioactivity in the experimental organism. The use of mixtures however, introduces difficulties into the interpretation and application of the results.

Fission product mixtures

When U^{235} contained in reactor fuel undergoes fission it produces a wide range of radionuclides. Each of these is produced at a certain rate and then begins to decay at its own characteristic rate, so that during the irradiation period there is a con-

stantly changing mixture of radionuclides. After the uranium has been removed from the reactor, fission ceases and the production of fission products is halted, but their decay continues. Since some decay with half-lives of minutes or days and some with half-lives of years or centuries, the mixture not only shows a continuing decline in radioactivity but also undergoes marked changes in composition.

Table 1 shows the changes that take place with time in a mixture of fission products derived from uranium that has been irradiated for 50 days in a reactor. The table has been simplified by listing only those fission products which constitute more than 5 per cent of the radioactivity (i.e. number of disintegrations per unit time) at one of the selected times.

The changes in elemental composition of the mixture over a period of 500 days are striking. Using the 50-day-old fission products one is studying accumulation of a mixture in which radioisotopes of niobim, zirconium and yttrium predominate, but at 500 days the major elements are cerium, praesodymium and promethium. It should be noted that if the irradiation period in the reactor had been different, then the initial (and subsequent) composition of the fission products would differ from that shown in Table 1. Further, in an actual radioactive waste stream the efficiency with which each element is extracted from the uranium fuel will introduce

Table 1. Composition of Fission Product Mixture†
(50 days irradiation)

	Percent of total radioactivity after decay of			
	50 days	100 days	250 days	500 days
Nb^{95}	15	22	21	*
Zr^{95}	14	15	10	*
Y^{91}	14	14	8.5	*
Ce^{141}	12	8	*	*
$Ce^{141} + Pr^{144}$	11	19	45	64
Sr^{89}	11	10	*	*
$Ba^{140} + La^{140}$	8	*	*	*
Ru^{103}	6.5	5	*	*
Pm^{147}	*	*	*	11
$Sr^{90} + Y^{90}$	*	*	*	6
$Cs^{137} + Ba^{137}$	*	*	*	6
Relative radioactivity	100	53	18	6
γ/β emission ratio:	0.57	0.48	0.40	0.15
Average β energy (MeV):	0.29	0.36	0.41	0.55
Average γ energy (MeV):	0.6	0.77	0.9	0.7

† Calculated using data from Fletcher[1] and Crouch[2].
* = less than 5 per cent of total radioactivity.

differences in composition, as will the presence of neutron-activated trace elements in the irradiated fuel and fuel jacket.

The determination of the radioactivity of the mixture is complicated by changes that take place in the average beta particle energy, gamma-ray energy and in the ratio of gamma emission to beta emission (Table 1). At 500 days the average beta particle energy is almost twice that of the mixture at 50 days. This means that most

detectors will count the older mixture with a higher efficiency; and the apparent decay of radioactivity will be less than the true decay. Similarly, the gamma emissions will be counted with different efficiencies at different times.

In addition to the above we have the known ability of organisms to accumulate very different amounts of different radionuclides. This means that the radionuclide mixture in the organisms will not have any obvious relationship to that in the water.

All of these considerations must be kept in mind when using mixtures of radionuclides or interpreting results of accumulation experiments in which mixtures have been used.

The interpretation of accumulation experiments

Even if accumulation experiments are confined to a single radionuclide there is great difficulty in translating the experimental results into useful information because an artificial ecosystem is such a poor simulation of a natural community.

In most such experiments the test organism is immersed in the radioactive solution for relatively short periods of time. After removal, the concentration of the radionuclide in the tissues is compared with that in the water and the result is expressed as a concentration factor [(μC/g organism)/(μC/ml of water)]. The concept of concentration factor could be valuable for predicting the consequences of radioactive pollution if it could be shown that it has a constant value for each radionuclide and a particular organism or tissue.

At Chalk River we (Ophel[3], Ophel and Judd[4, 5]) have carried out a number of experiments on the effects of environmental factors on accumulation of radiostrontium by fish. Some of these results can be used to demonstrate the difficulties in applying experimental concentration factors to natural ecosystems.

Effect of temperature

Figure 1 shows the rates at which Sr^{90} is accumulated from water by goldfish at four different experimental temperatures. For each 10°C increase in water temperature (within the tolerable range) the accumulation rate is approximately doubled. In Fig. 1 and subsequent figures each point on the graph is the mean of six fish.

Effect of cations

Figure 2 compares the accumulation rates of carrier-free Sr^{90} from water by fish in distilled water and in a solution of 1·0 meq Ca/1. After 15 days the concentration factor in the calcium solution is 8 while that in distilled water is 400. A similar depressing effect is observed with magnesium and strontium but not with potassium and sodium. If the Sr^{90} and the cations are incorporated in the fish food a similar reduction in the Sr^{90} accumulation takes place in the presence of the alkaline-earth cations (Ophel and Judd[5]).

Effect of starvation

When fish receive no food during the experimental period their rate of Sr^{90} accumulation is lower than those receiving a maintenance diet (Fig. 3). The depressed accumulation in starved fish is even more marked in distilled water, particularly at higher temperatures.

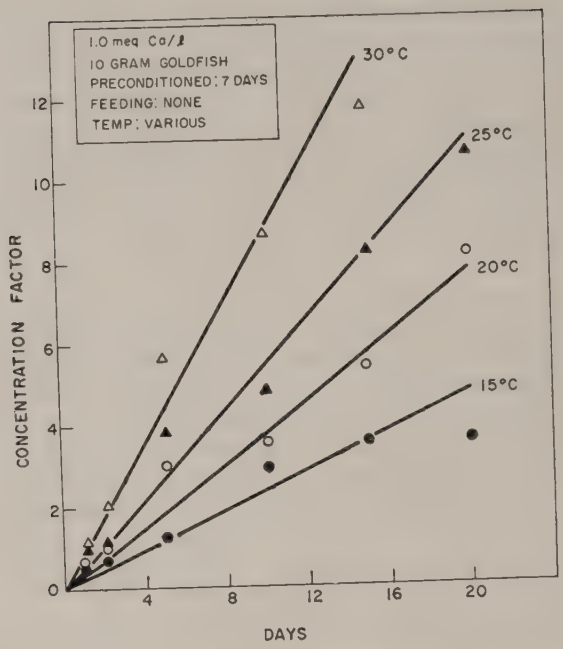

FIG. 1. Effect of temperature on Sr^{90} accumulation from water.

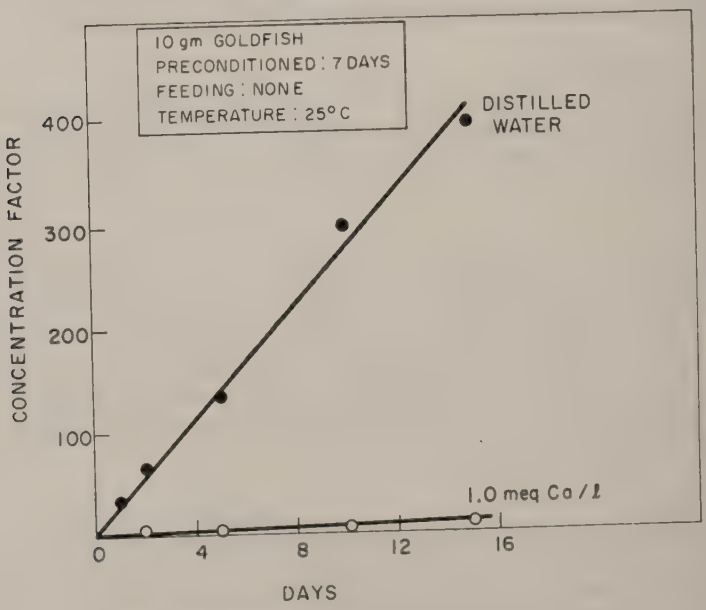

FIG. 2. Effect of cations on Sr^{90} accumulation from water.

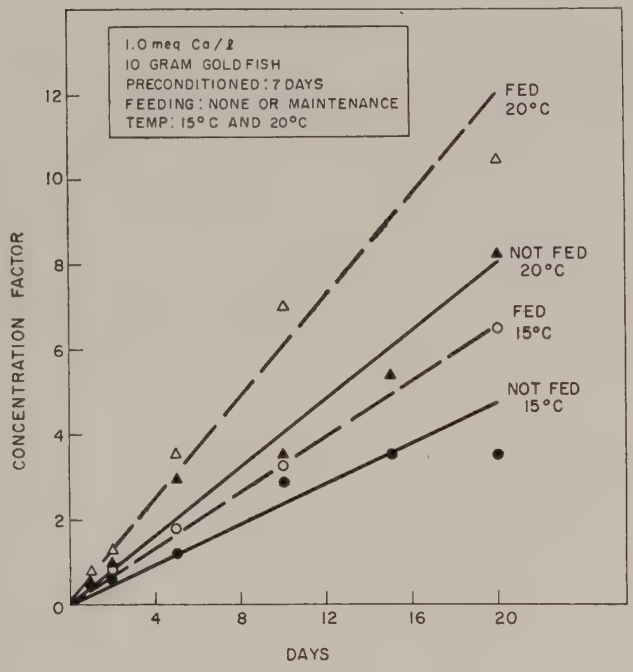

FIG. 3. Effect of starvation on Sr^{90} accumulation from water.

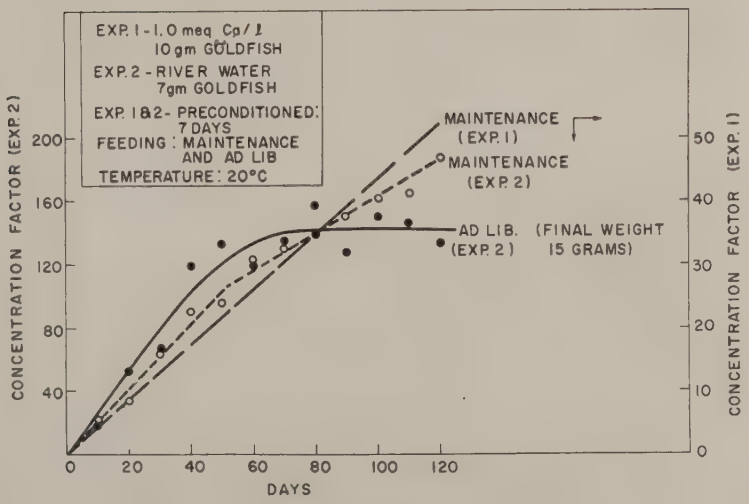

FIG. 4. Effect of growth rate on Sr^{90} accumulation from water.

Effect of growth rate

Longer term studies on the effect of growth rate on Sr^{90} accumulation are tedious and time-consuming but have given some interesting results (Fig. 4). If goldfish (av. wt. 7 g) are kept in contaminated water and are grown at the maximum possible growth rate by *ad libitum* feeding, they show an initial rapid accumulation of Sr^{90}. After approximately 50 days the rate of accumulation decreases and the rapidly growing fish show a relatively constant concentration factor. This levelling off is interpreted as "biological equilibrium", i.e. the uptake of Sr^{90} from the water by the fish is now equalled by the loss due to excretion.

However, if fish of the same size are maintained at a constant weight by feeding a maintenance diet, we find that biological equilibrium is not reached even after 120 days. The Sr^{90} concentration in the fish continues to increase at a constant rate throughout the 120 day period and eventually exceeds that of the rapidly growing fish.

The meaning of "concentration factor"

Using the experimental results outlined above, we can draw a series of accumulation curves for goldfish and Sr^{90} (Fig 5: A,B,C,D) any one of which represents a possible experimental answer. If some arbitrary exposure time is selected, we

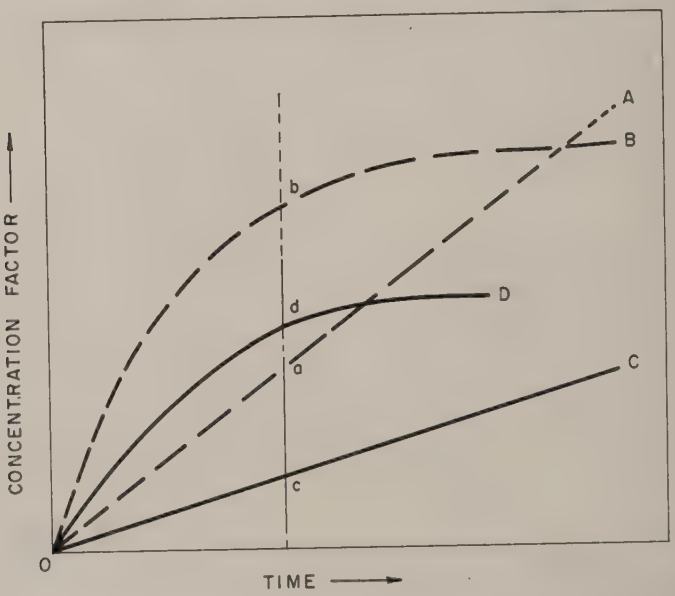

Fig. 5. Concentration factor versus time for various experimental conditions (see text).

obtain a series of different concentration factors (a,b,c,d) each representative only of particular experimental conditions. There is certainly no constant concentration factor even for a single fish species and one radionuclide.

We do know that, in a natural aquatic ecosystem, a trace element such as strontium has a certain concentration in the water and in the fish tissues. The ratio of these two values can be called the "true" concentration factor. When we add a radioactive isotope of strontium to the water and follow the accumulation of the isotope in the fish under laboratory conditions we are observing the exchange of the strontium in the water with that in the fish. The rate of accumulation of the tracer will be related to the metabolic turnover of strontium in the fish, and the concentration factor will be related to the availability or exchangeability of the fish strontium. Both the metabolic rate and the exchangeability vary throughout the life of the fish.

It follows that the only measure we have of the relation of the experimental concentration factor to the "true" concentration factor is a comparison of the specific activities (ratio of tracer atoms to stable atoms) of the water strontium and the strontium in the fish tissues. If the specific activities are the same, then exchange is complete, and we have a true concentration factor. If the tissue specific activity is lower it may be due to a number of causes such as; insufficient time for complete exchange, incomplete availability of the tissue strontium for exchange, or a slow rate of exchange in comparison with the half-life of the isotope.

If we make the tracer addition to the water of a natural ecosystem the situation is much more complicated. We how have many competing exchange reactions such as water ⇄ plants; water ⇄ sediments, etc., all competing with the water ⇄ fish system and all proceeding at different rates. Only after the specific activity of the stable element in the water has been maintained at a constant value for a long period of time, years in the case of strontium, will a true equilibrium be reached. At this time, of course, the specific activity of the element in all of the ecosystem parts will be the same as that in the water only if the half-life of the tracer is long in comparison with the time taken to reach equilibrium.

Any real advances in the prediction of the consequences of radioactive waste disposal into surface waters would seem to be bound up with detailed studies of stable element metabolism by aquatic organisms and the geochemical cycling of these elements.

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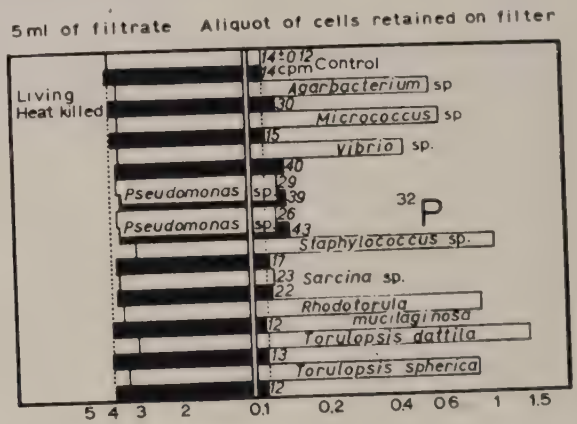
Explanation of figures

Seven strains of marine bacteria (*Agarbacterium* sp., *Micrococcus* sp., *Vibrio* sp.,

Pseudomonas spp., *Staphylococcus* sp., *Sarcina* sp.) and three species of marine yeasts (*Rhodotorula mucilaginosa*, *Torulopsis dattila*, *Torulopsis spherica*) cultured on agar were ready for preparation of cell suspension with sea water. Natural sea water filtered through Millipore filter (type HA) was used, after addition of Miquel's solution. The concentrations of cell suspensions were adjusted in colorimetric equivalence. Twenty four hours after addition of radionuclides (P^{32}, Sr^{85}, Sr^{89}, Sr^{90}, Y^{90}, Fe^{55}, CO^{60}, Zn^{65}, Cs^{134}), an aliquot of cell suspension was filtered through Millipore filter (type HA) with a pore size of about 0·45μ. And gamma-ray activities of filtrate and residue on the filter were separately determined with scintillation well-type counter. However, in the case of experiments on P^{32}, Fe^{55}, Sr^{89}-Sr^{90}-Y^{90}, beta-ray activities of samples were measured by Geiger-müller counter. In the figures, black columns indicate radioactivity carried out on the dead cell suspension, while white columns indicate radioactivity carried out on the living cell suspension. The term "heat killed" means that cells were killed by heating (95 C, 5 min.). (Numbers shown above columns indicate counts/min.)

FIG. 1.



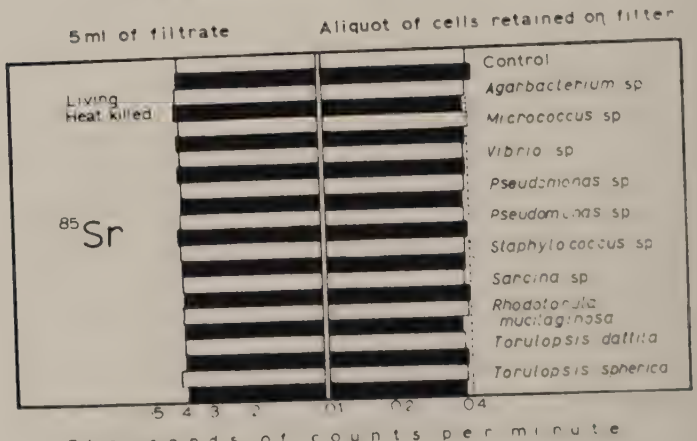
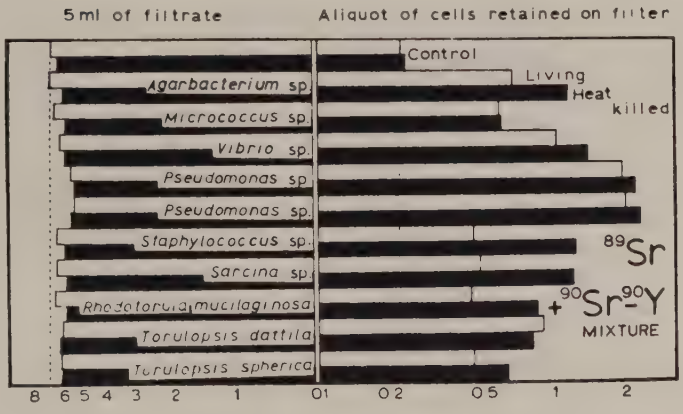


FIG. 2.



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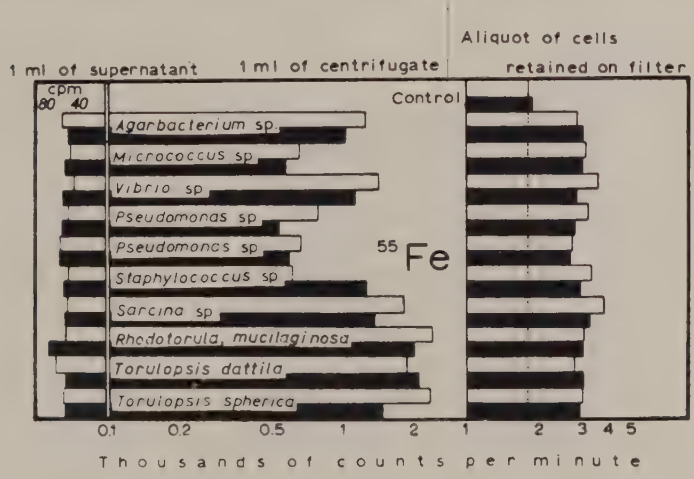

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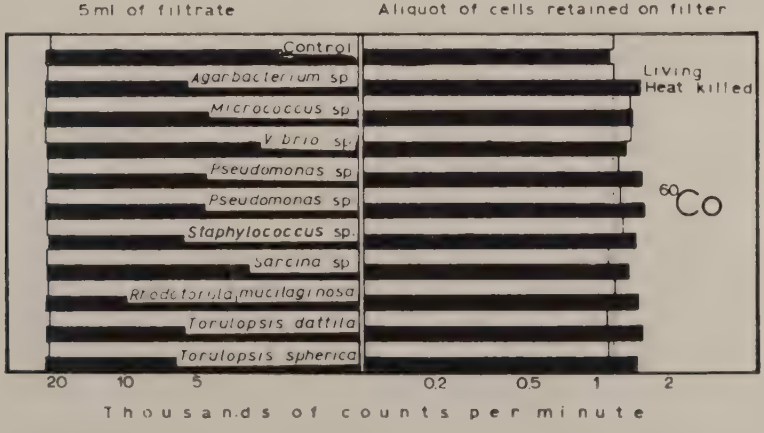

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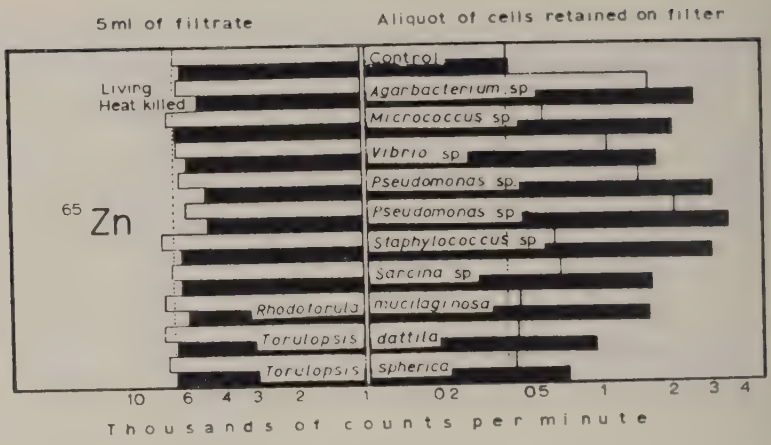

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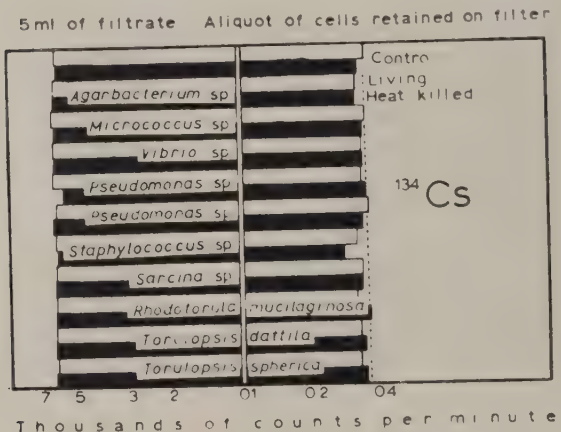

FIG. 7.

MASAMICHI SAIKI and TAKESHI UMEZU

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IT may be reasonable that data on the uptake of mixed fission products by marine organisms is needed rather than the data on individual radionuclides as suggested by Dr. RICE. However, we must keep in mind that induced radioactive materials such as Zn^{65} and Fe^{55}, which are rarely found in fission products, have a very important effect on the radioactive contamination of marine organisms. This effect is suggested

by our analytical results on fish caught in the Pacific Ocean. In this connection, our analytical data revealed that the liver of a highly contaminated big-eyed tuna, caught 80 miles from Bikini Atoll during October 1956, had the following radionuclide concentrations: 5×10^3 pc/g of Fe^{55}, 5×10^2 pc/g of Zn^{65}, $1{\cdot}2 \times 10^2$ pc/g of Cd^{115m}, 22 pc/g of Mn^{54}, 20 pc/g of Sr^{90} and traces of Ba^{140} and La^{140}. This data was of value in indicating the distribution pattern of radionuclides in fish. However, as stated, the analysis was carried out on a particularly highly contaminated fish, and does not represent the contamination level of fishery products from the Pacific Ocean in general, even of products taken after the atomic tests. Data collected from nineteen tunas caught in the mid-Pacific Area during August 1962, soon after the nuclear tests, are summarized as follows: 0·1–0·4 pc/g of Zn^{65}, 0·06–0·15 pc/g CO^{60}, $0{\cdot}3\text{–}1{\cdot}3 \cdot 10^{-1}$ pc/g of Sr^{90} and $4{\cdot}9\text{–}16{\cdot}7 \times 10^{-3}$ pc/g of Cs^{137}. Recently, Dr. Folsom presented the effect of radioactive waste effluents, in which he found that mussels, *Mytilus californianus*, collected at Newport, Oregon during 1963 were highly contaminated[3].

The role of phytoplankton on the cycle of radionuclides in a marine environment is clearly shown by Dr. Rice's experiments using bacteria-free culture. Therefore, we would like to add our experiments on the uptake of serveral radionuclides by marine bacteria and yeasts[4].

Finally we would like to emphasize the necessity of research on the effect of radionuclides on marine suspended matter. The percentage of microorganims in colloidal and particulate organic matter in sea water is very small[5] and according to observations carried out at oyster culture grounds, the largest portion of suspended matter observed consisted of minute chlorophyl-free particles while the remaining small percentage was occupied by phytoplankton[6]. It is concluded that the most effective accumulators of radionuclides in the oceanic realm are the mucous, ciliary and pseudopodial filtering members of the zooplankton family as suggested by Dr. Berner[7]. Drs. Krumholz, Goldberg and Boroughs also suggested that these organisms contained more radioactivity per unit weight than any of the algae, setal or rapacious feeders[8].

Since we are engaged in experiments on the uptake and transfer of radionuclides released into the sea from atomic energy industries, chiefly on the effect of suspended matter including plankton and bacteria, all of us acknowledge Dr. Rice's excellent work on plankton and other marine organisms. Also, we would be highly appreciative of receiving information on projects similar to our research program currently being carried out.

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FLOOR DISCUSSION

Y. Inoue: Marine organisms behave just as a synthetic ion-exchanger does to radioactive materials in water. Sr in sea water is in competition with the Ca or Mg ion and sometimes the following relationship is established when equilibrium is established: (Sr in water Sr in organism) (Ca in organism Ca in water) = constant (the parenthesis signify concentration) or (C.F.)Sr (C.F.)Ca = constant. The constant depends on the water temperature, pH, etc. Therefore (C.F.)Sr changes when calcium (stable) is added to sea water. Do you think that the measurement of this constant together with the measurement of C.F. is useful for investigation of the effects of radioactive nuclides in the ocean? Of course for some organisms this relationship cannot be applied.

I. L. Opuit: I cannot agree that living organisms can be equated with ion exchange resins because such organisms are growing and metabolizing many elements into their tissues. However, calcium and the other alkaline-earth elements do affect the accumulation of strontium and radiostrontium in fish tissues. Many other environmental factors also influence the accumulation. Whether the influence of alkaline-earth cations can be expressed in mathematical terms is an interesting question. I do not think it can be so expressed at the present time.

J. B. Sprague: In your slides you show "preconditioning" of animals for 7 days. Does this mean that they were held at the same temperature, water and feeding conditions as in the experiment? As you know, the acclimation to all such conditions could influence metabolism greatly. Have you more information on the effect of acclimation?

I. L. Opuit: The term "preconditioning" should be read as acclimation. We acclimated the fish to the experimental temperature, water and feeding schedule for 7 days. We did investigate the effect of acclimation periods up to 14 days and found that, at the experimental temperatures used, the 7 days' acclimation was sufficient.

Reprinted from Biological Bulletin, Vol. 128, No. 2, 315–327, April, 1965
Printed in U. S. A.

REPRODUCTIVE CYCLE OF MYA ARENARIA IN NEW ENGLAND

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Knowledge of the reproductive cycle in the soft-shell clam, *Mya arenaria* L., is essential to an understanding of larval production and ultimately of the abundance of this commercially important bivalve. By following the progress of gonad and gamete development in *Mya* throughout the year, the times and duration of spawning can be determined—information useful in the management of this fishery.

Although the literature contains numerous references to the times of spawning, information about gonadal changes in *Mya* is fragmentary or incomplete. We found the smear technique, used by Battle (1932), unreliable for determining gamete development because important details seen in the histological preparations were obscure in fresh, unstained smears. Coe and Turner (1938) described the development of juvenile *Mya* and gametogenesis from histological preparations. Unfortunately, their study indicated only the beginning of spawning and gave no data on its duration. In a preliminary report, Rogers (1959) described gonad development in Chesapeake Bay, Maryland, during the summer and fall. He observed a fall spawning period and ventured an opinion that a spring spawning also occurred, but he had not completed a full year of observations. Pfitzenmeyer (1962) also reported preliminary histological observations to support a conclusion that Maryland clams have two separate maturations.

Plankton studies by various investigators have revealed both annual and biannual periods of larval abundance. Both Stevenson (1907) and Stafford (1912) reported their observations of larvae as most numerous during a single period of time. Sullivan (1948) used the term "broods," possibly to describe successive large groups of larvae, but did not mention intervals between the groups when none were caught. Landers (1954) observed both an early-major and later-secondary larval occurrence. Between the two swarms, larvae disappeared for intervals of one to two months. Pfitzenmeyer (1962) observed an early-secondary and later-major larval occurrence. Larvae were not caught for intervals of three to four months between these biannual swarms.

Inferences about the frequency of spawning have also been made from observations of the first appearance of newly settled juveniles in the flats. Successive ripening and spawning periods during a single reproductive cycle were hypothesized by Belding (1930) to explain the "not uncommon" occurrence during any one year of "two distinct sets" in areas on the southern shores of Cape Cod. Pfitzenmeyer (1962) used special collectors in Chesapeake Bay and obtained two distinct sets of juvenile clams each year. A period of two to three months when none were caught separated the biannual settings.

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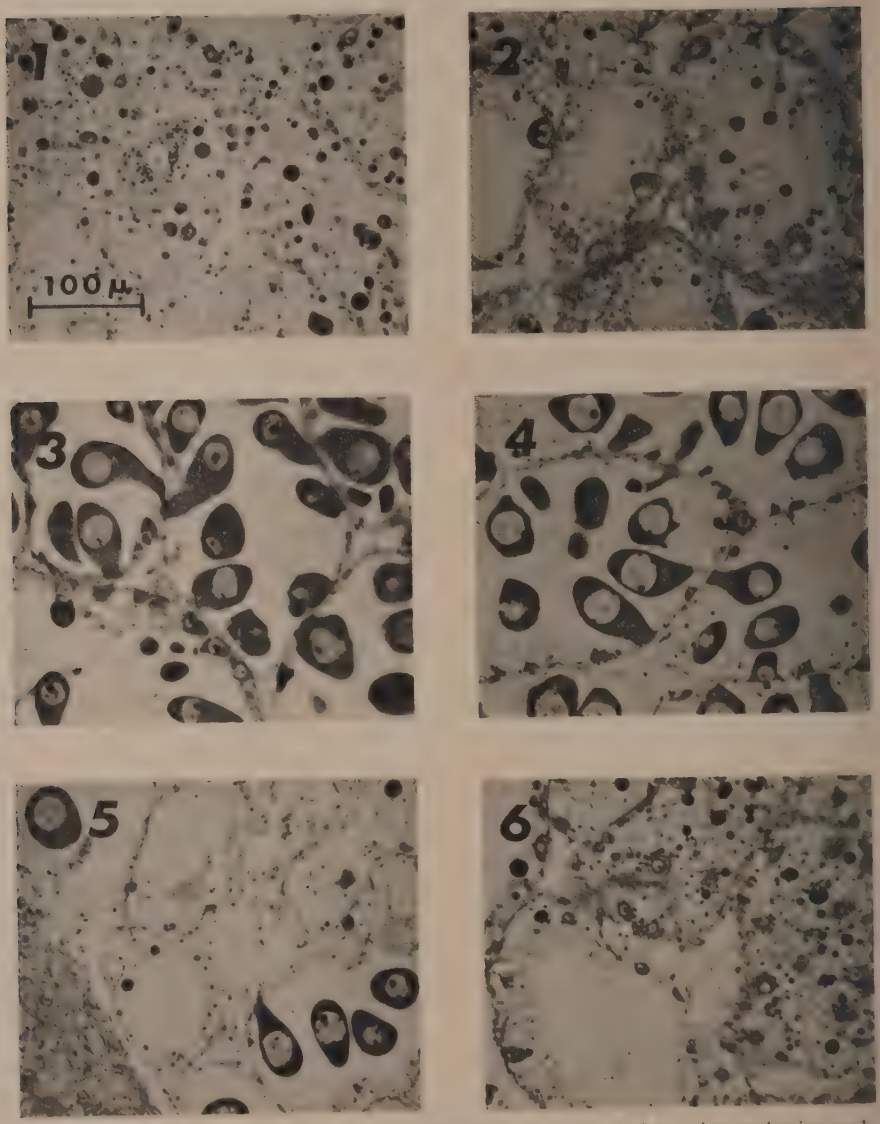


FIGURE 1. Section of gonad tissue from female clam, inactive phase of reproductive cycle. Note the small, dark phagocytes in the center of the alveolus, nutritive inclusions scattered within the follicle cells, and a large, round, almost completely cytolyzed ovocyte. To permit a comparison of cell size during maturation, all the photomicrographs were taken at the same magnification and a scale (100 μ) is provided.

FIGURE 2. Same, from female clam in active phase, showing early stages of ovogenesis.

FIGURE 3. Same, from female clam in active phase, showing later stages of ovogenesis.

Unfortunately, no certain conclusions about the nature of the reproductive cycle itself can be drawn from observations of either planktonic larvae, or newly metamorphosed set, since several seasonal peaks of abundance may appear from spawnings resulting from a single annual reproductive cycle. While observations of larval swarms can provide corroborative evidence, the annual frequency and duration of the reproductive cycle of clams can best be learned from periodic histological examinations of their gonad tissue. This paper presents the results of such studies made on clams from several New England areas.

Methods

Collections of clams were obtained periodically from the following New England areas north of Cape Cod. Plum Island Sound clam flats in Newbury, Massachusetts, were sampled twice each month from April, 1951, through February, 1953; flats near Boothbay Harbor, Maine, from February to November, 1961 (except April); and flats in Sorrento, Milbridge, Roque Bluffs, Cutler, Lubec, Pembroke, and Robbinston, Maine (collectively designated as eastern Maine in the text), each month from September, 1959, through December, 1960. The clams were dug from the middle of the intertidal zone in the eastern Maine and Boothbay Harbor areas, but throughout the whole intertidal zone in Plum Island Sound because the clams were not abundant. Miscellaneous collections were also obtained from Falmouth and Woods Hole, Massachusetts. These samples from areas on the south side of Cape Cod provided valuable supplementary data. Each sample included approximately 10 clams, $1\frac{1}{2}$ to 3 inches in shell length.

Within a few hours after field collections were made, the anterior third of the visceral mass of each clam was removed and preserved in Bouin's fixative. Standard techniques of dehydrating in alcohol, imbedding in paraffin, sectioning at 10 μ, and staining in Delafield's hematoxylin and eosin were used to prepare slides of the gonad tissues.

A microscopic examination was made to assign each specimen to a category which represented the gonad condition. The proportion of clams in each category, regardless of sex, was recorded for the individual samples. Although minor differences were observed, data on the clams from the seven eastern Maine sample areas, as well as the twice-a-month samples from Plum Island Sound, were combined each month to simplify presentation. Since the combined samples had no single collection date, a date midway between the first and last collection dates was chosen to represent each month's observation of gonad condition.

Categories of Gonad Condition

Female gonads

Except for certain pre-meiotic stages, ovocyte maturation occurs not in the ovaries, but after the eggs are shed (Raven, 1958). Therefore, tissues could not be classified according to the meiotic stages of the ovocytes. Instead, arbitrary

Figure 4. Same, from female clam in ripe phase. Note the amphinucleoli in the centrally located ovocyte.

Figure 5. Section of gonad tissue from female clam in partially spawned phase.

Figure 6. Section of gonad tissue from spent female clam. Note the small ovocytes at the periphery of the alveoli.

categories of development were distinguished by dividing the more or less continuous reproductive process into five phases. These are described below.

1. *Inactive phase*

At certain times of the year the rate of gonad activity becomes so low that changes in appearance of the gonad tissues in successive samples are imperceptible. Therefore, this state of relative quiescence is hereafter termed the inactive phase of the reproductive cycle. The term, however, is used for convenience and is not meant to imply that no activity at all is taking place. Small ovocytes occur at the periphery of alveoli (Fig. 1). A round nucleus in the ovocyte contains a conspicuous basophilic nucleolus and is encircled by an irregularly shaped cytoplasm. Vacuolated follicle cells that completely imbed the ovocytes sometimes fill the lumina of alveoli. Inclusions, apparently nutritive in function (Coe and Turner, 1938), frequency occur in the follicle cells. Small migratory cells sometimes appear between alveoli and within the lumina of alveoli. These migratory cells are probably phagocytic for they surround cytolyzed, unspent ovocytes.

2. *Active phase*

That part of ovogenesis which takes place within the gonad tissue and where definite quantitative and qualitative changes in the ovocytes are perceptible is designated as the active phase of the reproductive cycle. Enlarging ovocytes grow between the follicle cells toward the centers of alveoli during the early stages (Fig. 2). These ovocytes, which may be sub-conical, hemispherical or cylindrical in shape, are characteristically rounded at their apices and have broad cytoplasmic bases attaching them to the wall of the alveolus. The nuclei measure from 8 to 16 μ and average 13.3 μ in diameter.

Subsequent growth produces large, round ovocytes with constricted cytoplasmic bases (Fig. 3). The free ends of ovocytes extend beyond the basal membrane of follicle cells into the lumina of alveoli. The nuclei measure from 15 to 23 μ and average 19.2 μ in diameter. These ovocytes occur late in the active phase.

The onset of ovogenesis is difficult to determine with precision, as pronounced changes in staining reactions do not occur. However, the slight enlargement of many ovocytes, the more regular shape of their cytoplasm and protrusion toward the alveoli centers are visible indications of growth activities. Thereafter, the growth of ovocytes and tissue changes are more definite.

3. *Ripe phase*

In ripe clams, a very slender stalk may connect many of the largest ovocytes to the basal membrane (Fig. 4). Other ripe ovocytes appear as round cells in the lumina of alveoli, as if free of attachment to the basal membrane. The nuclei of these largest ovocytes contain amphinucleoli (Allen, 1953), each consisting of an almost transparent nucleolus and a small opaque nucleolinus. The amphinucleolus resembles a signet ring in some sections because the smaller nucleolinus occurs at the periphery of the nucleolus. The nuclei of ripe ovocytes measure from 20 to 31 μ and average 28.2 μ in diameter. These large ovocytes fill the lumina of alveoli and are usually more numerous than less developed ovocytes.

4. *Partially spawned phase*

In partially spawned clams, gonad tissues contain a few ripe ovocytes in some of the alveoli (Fig. 5). Small ovocytes are imbedded in follicle cells at the periphery of empty alveoli. Nutritive inclusions appear in many of the follicle cells. An absence of ripe ovocytes in many alveoli and the cessation of ovogenesis in all alveoli is indicative of the partially spawned condition.

5. *Spent phase*

Follicle cells form a thin layer covering the basal membrane of alveoli in some spent tissues, while in others they fill the alveoli (Fig. 6). Spent individuals can be distinguished from those in which no gametogenesis has taken place at all by the presence of a few unspent ovocytes in the early stages of cytolysis, which appear in the lumina of some alveoli as large, darkly stained bodies with obscure nuclei. Also, very numerous spherical droplets of lipoids and other products of cytolysis are characteristic of individuals which have completed a period of ovogenesis and have spawned (or, when conditions were not conducive for spawning, have resorbed their gametes).

Since the reproductive process is cyclic, the spent phase merges with and overlaps somewhat the inactive phase. Sharp distinction between the two is a convenience rather than a natural phenomenon.

Male gonads

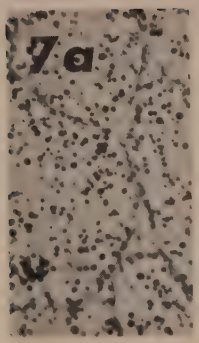
The criteria for the five corresponding categories of gonad condition in the male are presented below.

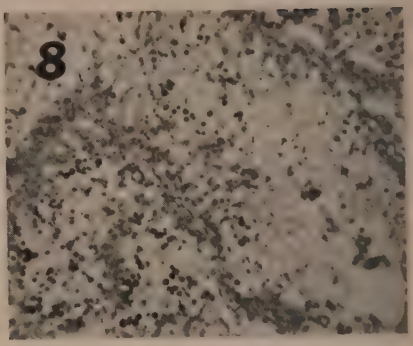
1. *Inactive phase*

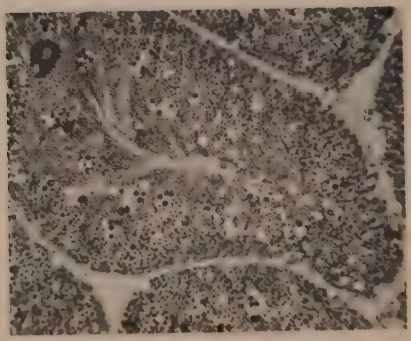
During the inactive phase, the male tissues frequently contain the products of an aberrant meiotic activity, which Coe and Turner (1938) have called "atypical spermatogenesis." Pycnotic cells (Fig. 7a) and multinucleated, non-pycnotic cysts (Fig. 7b) appear in the follicle cells. Many tissues contain both types although one usually predominates over the other. Both types of inclusions disappear during normal spermatogenesis, but reappear before it ceases, as do the nutritive granules seen in female tissues. Follicle cells fill the alveoli, surround the aberrant cells, and imbed the few spermatogonia and primary spermatocytes at the periphery of alveoli.

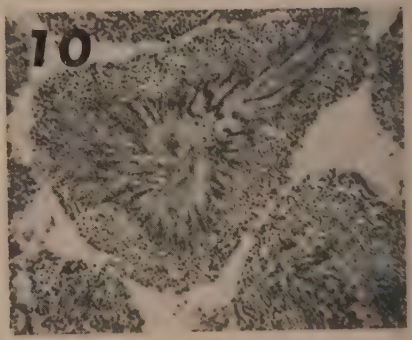
2. *Active phase*

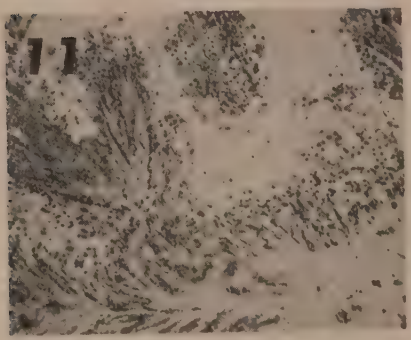
The active phase of the reproductive cycle in the male includes the entire process of spermatogenesis, unlike that in the female where only pre-meiotic stages are included. At the onset of the active phase, tissue sections contain proliferating primary spermatocytes at the basal membrane of the alveoli (Fig. 8). These small and uniformly sized cells, very similar in appearance to the earliest ovocytes, force their way between follicle cells and toward the centers of alveoli. Early stages of meiosis occur in the spermatogenic cells near the basal membrane, whereas the











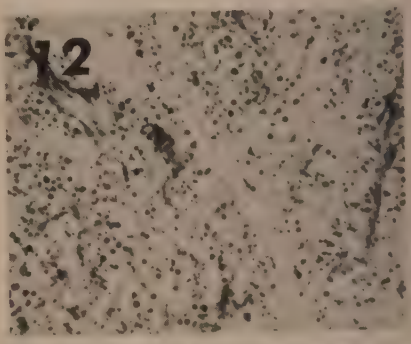


FIGURE 7a. Section of gonad tissue from male clam in inactive phase of reproductive cycle. Inactive phase of spermatogenesis in male soft-shell clams. Note the round, pycnotic cells, products of atypical spermatogenesis.

FIGURE 7b. Same, showing the cysts of multinucleated, non-pycnotic cells, also products of atypical spermatogenesis.

FIGURE 8. Section of gonad tissue from male clam in active phase of reproductive cycle, showing early stages of spermatogenesis.

FIGURE 9. Same, showing later stages of spermatogenesis. Late, active phase of spermatogenesis.

later spermatids occur at the centers of alveoli (Fig. 9). A very thin-walled membrane surrounds each spermatid. Meiotically active cells between the periphery of the alveoli and their centers eventually obliterate the follicle cells. A large number of spermatids produce a distinct mass in the centers of alveoli.

3. *Ripe phase*

Ripe male tissues contain masses of spermatozoa, arranged in more or less radial columns with their tails oriented toward the center. In fully ripe specimens these spermatozoa may nearly fill the lumina of the alveoli (Fig. 10).

4. *Partially spawned phase*

Partially spawned male tissues contain relatively few spermatogonia at the basal membrane (Fig. 11). Follicle cells occur between the basal membrane and groups of cells undergoing spermatogenesis. A scattering of pycnotic cells occur within the follicle cells. Spermatozoa still occupy a substantial portion of the central alveolar area.

5. *Spent phase*

Spent male tissues contain no or very few spermatozoa in the central alveolar area (Fig. 12). Numerous follicle cells with multinucleated, non-pycnotic cysts and pycnotic cells from atypical spermatogenic activities surround small groups of spermatozoa. Spent tissues lack cells in the active phase of spermatogenesis.

Geographic Variations in the Reproductive Cycle

Eastern Maine

Clams in the inactive phase were encountered throughout the year in eastern Maine, but were least numerous during June (Fig. 13). All were in this condition from September through December in 1959 and 1960. By January, 1960, some had begun gametogenesis. Clams in the active phase became more numerous each month after January, until May, after which fewer individuals were in this condition, and were absent from the August samples. Clams in the active phase were obtained to some extent for a period of about seven months.

Ripe clams were first observed in the middle of May, but none showed indications of having spawned. In June about half of the clams were ripe and some were partially spawned. Partially spawned clams were more numerous in July and by August about 75% of the clams had completely spawned and had returned to the inactive condition. The spawning period, then, extended from early June to about the middle of August, a period of 2½ months.

Minor exceptions to the reproductive cycle described above were observed in clams from two eastern Maine areas where gametogenesis began earlier than in the

Figure 10. Section of gonad tissue from ripe male clam. Note the columns of spermatozoa.
Figure 11. Section of gonad tissue from male clam in partially spawned phase.
Figure 12. Section of gonad tissue from spent male clam. Note the occurrence of both types of atypical spermatogenesis.

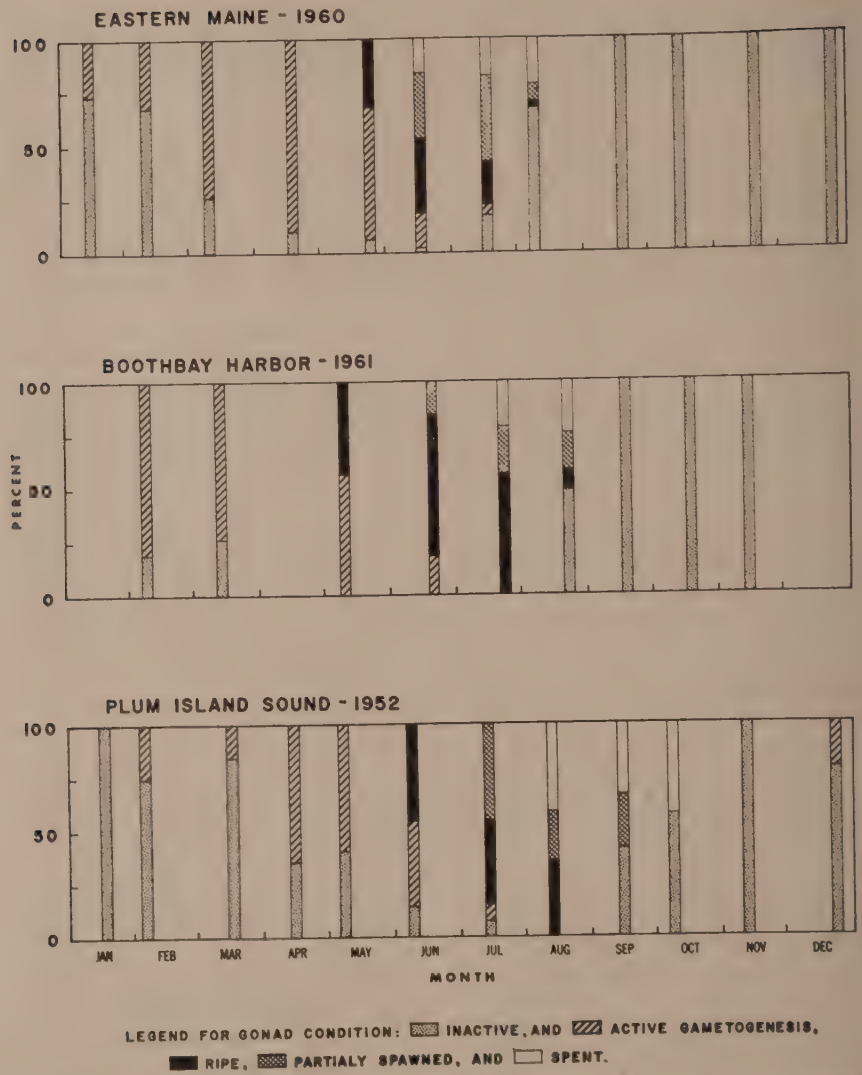


FIGURE 13. Gonad conditions of *Mya arenaria* from New England. The length of each shaded area represents the percentage frequency of clams in each gonad condition.

five other areas. More than half of the Lubec and Pembroke clams were in the active phase in January and February. After February, clams in this condition were almost equally as numerous from all seven eastern Maine areas. An earlier spawning in Lubec and Pembroke was not definitely indicated by the data.

Boothbay Harbor

Gametogenesis had commenced in about 75% of Boothbay Harbor clams during February and March (Fig. 13). More ripe clams occurred during May in the Boothbay Harbor than eastern Maine samples. Some partially spawned clams were observed as early as June in Boothbay Harbor, but both areas yielded numerous partially spawned clams during July. Completely spawned clams did not appear until July in Boothbay Harbor, or nearly one month later than in eastern Maine. More Boothbay Harbor than eastern Maine clams were in the ripe, partially spawned or spent condition in late August. The three-month spawning period of Boothbay Harbor clams, extending from late June to August, was not only later, but longer by a half a month than that of eastern Maine clams.

Plum Island Sound

The spawning season was still later in clams from Plum Island Sound than in clams from all Maine study areas (Fig. 13). Relatively few clams began gametogenesis during February and March. Ripe clams appeared first in June, a month later than clams from Maine. Correspondingly, the earliest occurrence of spawned clams was later. Spawning, indicated by the appearance of partially spawned clams from July through September, lasted for three months in Plum Island Sound. Many spent clams were seen as late as October.

Discussion

The results of gonad examinations suggested several generalizations about the reproductive cycle of *Mya arenaria*. Gametogenesis began during the late winter or early spring in all areas sampled. Thereafter a progressive development of the gametes was seen until ripe cells filled the tissues and spawning began in late spring and early summer. A spawning peak occurred during the middle and late summer, after which gametogenesis ceased. The inactive condition prevailed during the fall and most of the winter. No more than a single reproductive cycle occurred in the clams from nine sample areas north of Cape Cod. No failure to spawn was indicated in clams from any of the sample areas.

Despite the more southern latitude, the reproductive period in Plum Island Sound was characterized by a later rather than an earlier spawning season than that in Maine (Fig. 13). Furthermore, a still later spawning season than that of 1952 was indicated by the occasional gonad samples taken in Plum Island Sound during the preceding year. A few ripe clams first appeared during July, 1951. Both ripe and partially spawned clams were most numerous during late July and early August. All were spent by late October, 1951.

Most reports of larval occurrence and sex cell development indicated that *Mya* begins spawning at an earlier date in areas north of Plum Island Sound (Fig. 14). At Malpeque Bay, Canada, the earliest soft-shell clam larvae were found during early June by Stafford (1912) and during late May by Sullivan (1948). Stafford (1912) found an abundance of *Mya* larvae during July and August at St. Andrews, Canada. Most of the clams in Battle's (1932) samples from St. Andrews, Canada, contained ripe gonads during early June. She found some spent gonads by late June, indicating the beginning of the spawning season.

After finding an early abundance of larvae, Welch (1953, unpublished report) [2] deduced that some were probably in the plankton of Robinhood Cove, Maine, during early May, 1951. He also caught a few larvae during June of 1952 (oral communication), even though maximum numbers occurred during the middle of August to the middle of October that year.

A late spawning season was reported for *Mya* in northern Massachusetts areas. Belding (1907) observed that *Mya* spawns from the middle of August until early October (Fig. 14). Stevenson (1907) caught no larvae at Ipswich, Massachusetts, before late August, and reported the last half of September as the period of peak spawning. He also caught large numbers of larvae at Plymouth, Massachusetts, during late July and early August. Later Belding (1930) reported July and August as the spawning season for soft-shell clams north of Boston. These reports agreed with our observations of a late active phase and spawning period of *Mya* in Plum Island Sound.

A study of Figure 14, summarizing available information on the reproductive cycle of *Mya*, shows clearly two important phenomena: (1) the tendency for clams to develop gametes and spawn progressively earlier in the season northward and southward from northern Massachusetts, and (2) the bimodal nature of spawning activity south of Cape Cod. It is not entirely certain from this information that the bimodality results from two distinct reproductive cycles. It may result merely from an interruption in the spawning activity during a single reproductive cycle. Lacking observations on gametogenesis in the clams from their study areas, Bumpus (1898), Mead and Barnes (1904), Belding (1907; 1930), Stevenson (1907), Nelson and Perkins (1931), Deevey (1948), and Landers (1954) neither described nor implied more than a single annual reproductive cycle to *Mya*, even though Mead and Barnes (1904), Belding (1907; 1930), and Stevenson (1907) found two distinct groups of newly settled juveniles, and Landers (1954) observed two distinct swarms of larvae. In addition, Coe and Turner (1938) and Rogers (1959) believed that *Mya* probably spawned more than once each year, but did not mention the possibility of more than a single annual reproductive cycle.

Nevertheless, some evidence is available from several studies which suggests two separate reproductive cycles per year in southern latitudes. The clams from southern areas were reported to begin spawning earlier in the year than those from northern Massachusetts areas (Fig. 14). Deevey (1948) found that *Mya* larvae were dominant in Tisbury Great Pond on Martha's Vineyard, Massachusetts, from late April to June. Landers (1954) obtained larvae as early as the middle of April in samples from Wickford Harbor, Rhode Island, whereas Pfitzenmeyer (1962) captured larvae in the plankton of Chesapeake Bay, Maryland, throughout May. More important, however, both Landers (1954) and Pfitzenmeyer (1962) caught no larvae during the middle of the summer, after a late spring to early summer larval swarm. This period of larval absence in the plankton corresponded to observations of gonads by Rogers (1959) and Pfitzenmeyer (1962) which were apparently in the inactive phase during the middle of

[2] Welch, W. R., 1953. Seasonal abundance of bivalve larvae in Robinhood Cove, Maine. Fourth Annual Conference on Clam Research, U. S. Fish and Wildlife Service, Clam Investigations, Boothbay Harbor, Maine. (Mimeographed report).

the summer. Hence, the clams were unable to spawn because ripe sex cells were not present in the gonads.

Further evidence of biannual spawning can be drawn from our own histological examinations of clams collected in the Woods Hole, Massachusetts, area.

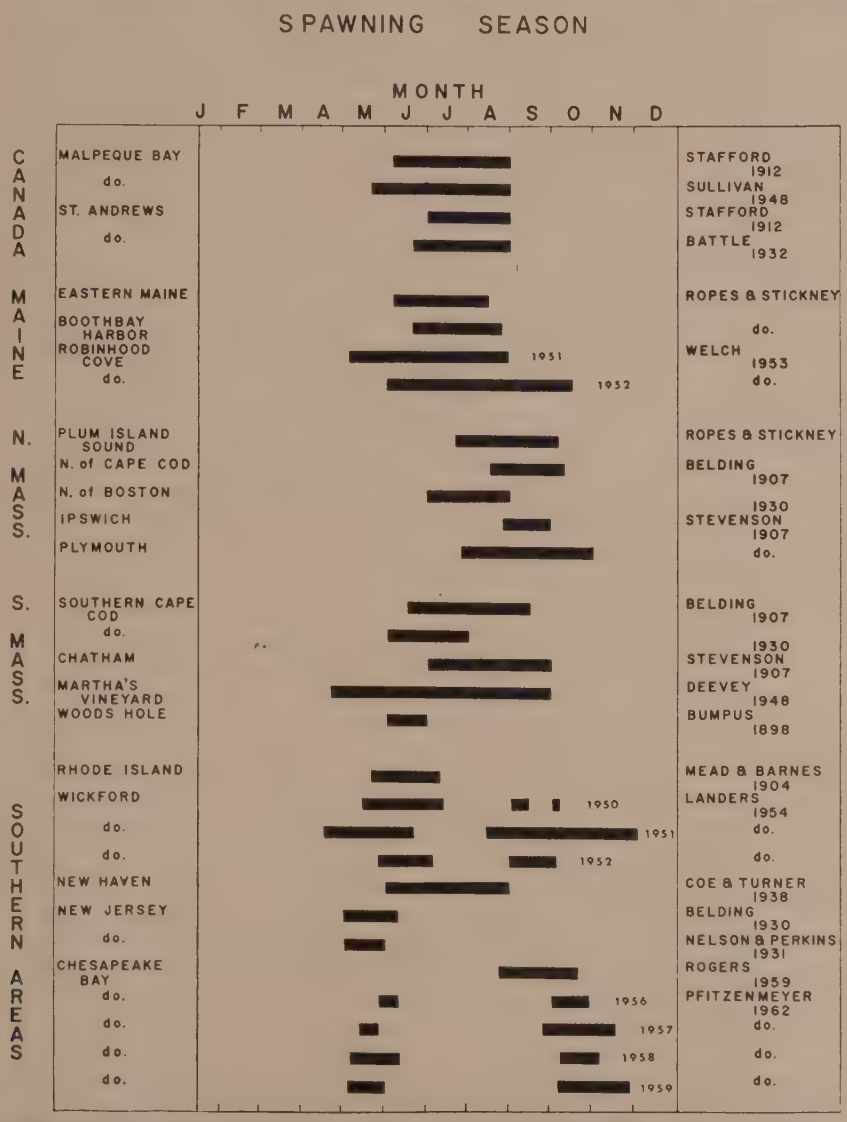


FIGURE 14. The duration of the spawning season of *Mya arenaria* reported in the literature for areas along the Northwestern Atlantic coast.

Samples of clams collected July 19 and 31, 1950, from Falmouth Inner Harbor contained none with ripe or developing gametes. Some live clams from these samples were held in outdoor tanks of sea water at seasonal temperatures until September 1, 1950, at which time most of them were fully ripe. The numerous nutritive granules, typically products of cytolyzed, unspawned gametes in females and the products of aberrant spermatogenesis in males, which were seen in July samples suggest that the clams from this population had also been ripe earlier in the year. This inference was supported by subsequent observations of ripe clams which were common in samples collected from Woods Hole both in late September, 1961, and in late May, 1962. The occurrence of ripe gonads during the early spring and fall corresponded to the times when larval swarms were found by both Landers (1954) and Pfitzenmeyer (1962). When the gonads of clams in the southern latitudes were in the inactive condition the gonads of clams in the northern latitudes were either ripe or partially spawned. Therefore, the two periods of gametogenesis in clams from southern areas were completely out of phase with the single annual reproductive period of northern clams, and indicated a biannual reproductive cycle.

We used clams with an apparent biannual reproductive cycle in spawning experiments at the Boothbay Harbor laboratory. Spawnings were induced during a period of a month or more after collecting clams from Woods Hole, Massachusetts, in late September, 1961, and also in late May, 1962, as well as from Chesapeake Bay, Maryland, in the middle of October, 1961. The Maryland clams remained in the inactive condition during the winter, and ripened again the following April in the laboratory tanks. These clams produced larvae when local clams were neither ripe enough to spawn, nor were the gametes developed to the ripe condition by the methods we tried.

We wish to thank Mr. Malcolm E. Richards, Marine Resources Scientist of the Maine Department of Sea and Shore Fisheries, for providing us with gonad samples from eastern Maine.

Summary

1. Only a single reproductive cycle was observed in *Mya arenaria* gonads collected from areas north of Cape Cod.

2. In eastern Maine, the spawning season extended from early June to the middle of August. Boothbay Harbor clams spawned from late June to late August. Clams from Plum Island Sound began spawning in July, a month later than eastern Maine clams, and completed spawning by late September.

3. Observations of gonadal changes in *Mya* from southern Cape Cod indicated a biannual cycle occurs. These observations are supported by previous reports of spawning activities, larval occurrence, and gametogenesis in *Mya* from the southern latitudes.

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Reprinted from THE JOURNAL OF WILDLIFE MANAGEMENT
Vol. 29, No. 3, July 1965
pp. 448–463

EVOLUTION OF FUR SEAL MANAGEMENT ON THE PRIBILOF ISLANDS

BY ALTON Y. ROPPEL AND STUART P. DAVEY

EVOLUTION OF FUR SEAL MANAGEMENT ON THE PRIBILOF ISLANDS

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Abstract: Management of the northern fur seal (*Callorhinus ursinus*) and development of techniques from indiscriminate killing to present-day harvesting of specific sex and age-groups are traced. Restricted to breeding on the Kurile, Robben, Commander, and Pribilof islands, fur seals were twice exploited almost to extinction before international protection was assured in 1911. Various controls used to regulate the kill of male seals on the Pribilof Islands since 1870 have included quotas, limitations on body length and skin weight, selection by age and secondary sex characteristics, and changes in length of killing season. Analysis of the kill and counts of live pups from 1912 to 1922 resulted in use of a 6–8 percent factor to calculate annual herd growth until 1948, when the system was abandoned as unrealistic. An average annual kill of 66,000 young males from 1939 to 1956 decreased to 48,000 annually from 1957 to 1964. Length classes were used from 1918 to determine the ages of seals until discovery in 1950 of a technique using annual growth layers on the roots of canine teeth. Management policies were revised in 1956 to permit a restricted kill of females. Since that year, 286,506 females have been taken on land. The kill of females has been controlled by quotas and by selection on the basis of body length and vibrissal color. It has been recently calculated that 9,000–18,000 females can be taken annually on the Pribilof Islands on a sustained basis.

This paper traces the management of the northern fur seal and shows the evolution of techniques directed toward attaining maximum sustained productivity of the resource.

The story of fur seal management reflects in many ways the strengths and weaknesses of men. Lust and greed were evident during periods of herd depletion; later, sentimentality and overcaution created management problems during recovery periods. The history of fur seals also reflects the evolution of wildlife management and shows man's resistance to change.

Northern fur seals breed on the Robben, Commander, and Pribilof islands, and are becoming reestablished on the Kurile Islands. The total population numbers nearly 2 million, of which more than 80 percent return annually to the United States-owned Pribilof Islands (Fig. 1).

The fur seal resource is of international concern. In 1957, members of the North Pacific Fur Seal Commission, representing Canada, Japan, the U.S.S.R., and the United States, ratified a 6-year Interim Convention on Conservation of North Pacific Fur Seals (U. S. Congress, Senate 1957). The Convention provided that, in lieu of pelagic sealing rights, Japan and Canada each receive 15 percent of the skins harvested by the United States and the U.S.S.R., with certain exceptions for sharing of the U.S.S.R. harvest dependent on the level of pelagic research conducted in the western Pacific Ocean. A 6-year extension effective in 1964 (U. S. Department of State 1964) reduced the Japanese and Canadian share of skins from the U.S.S.R. to 10 percent for the first 3 years, followed by an increase to 15 percent for the remaining 3 years of the extension. The reduction is intended to permit more equitable distribution of profits from seals harvested on Soviet islands.

The value of northern fur seal remains high. At auctions held in October, 1963, 20,345 skins from young males and 4,734 from females brought an average price of $111.72. Under the terms of the Alaska Statehood Act, the state of Alaska receives

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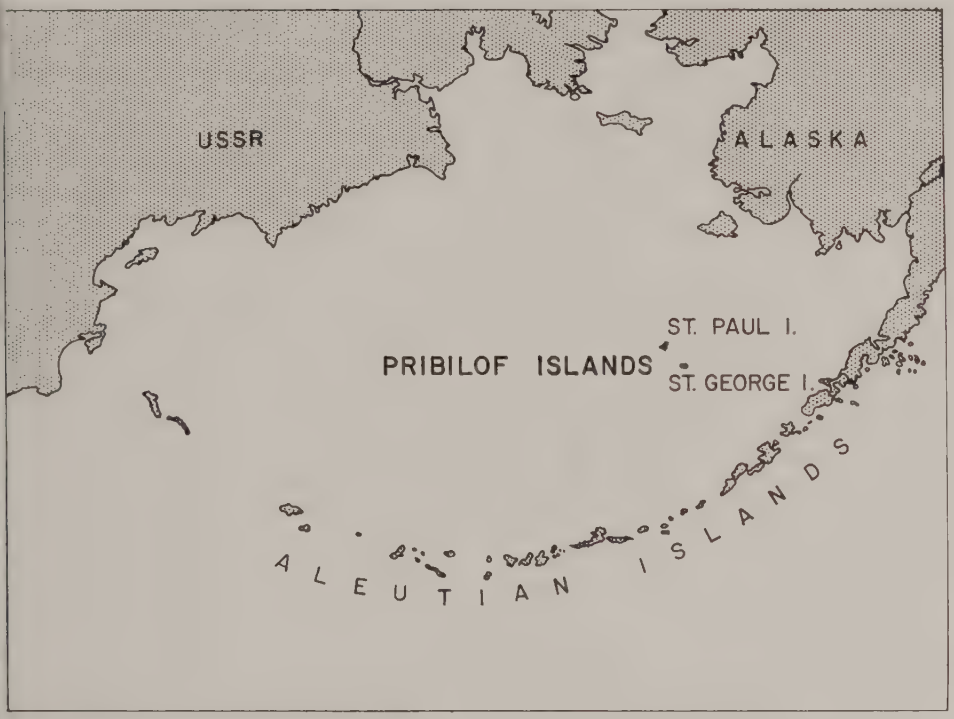

Fig. 1. Geographic location of Pribilof Islands, Alaska.

70 percent of the net proceeds accrued to the U. S. Treasury.

In 1867, Russia ceded the Pribilof Islands to the United States as part of the $7,200,000 Alaska purchase. Immediate responsibility for fur seal management was vested in the Department of the Treasury from July 27, 1868, to July 1, 1903, when the newly formed Department of Commerce and Labor took charge. Various officers of this Department managed the seals until transfer of the function on December 28, 1908, to the Bureau of Fisheries (established 1903). Later (June 30, 1940), the Bureau of Fisheries was combined with the Department of Agriculture's Bureau of Biological Survey to form the Fish and Wildlife Service in the Department of Interior. Effective November 6, 1956, a Bureau of Commercial Fisheries was established within the Fish and Wildlife Service. This Bureau presently conducts both research and management pertaining to the fur seal.

About 600 Aleuts residing on St. Paul and St. George islands are historically involved with fur seals, since they are descendants of people brought to the Pribilof Islands from Atka and Unalaska by the Russians (Elliott 1884:19). Many of these Aleuts are employed today in the fur seal industry of the Pribilof Islands at prevailing Alaska wage rates. Contrary to their ill-fated ancestors, who lived in oil-blackened sod huts and in complete servitude to their Russian masters, the Aleuts of today enjoy modern frame houses and labor-saving devices found in the average American

home. None are dependent on local sources of food (fish, berries, fur seal, and sea lion (*Eumetopias jubata*) meat), although these resources receive some attention, primarily recreational. Many modern Aleuts receive high school diplomas, and a few go on to trade schools or to universities.

HISTORICAL (1786–1869)

Following the rapid decline of the sea otter (*Enhydra lutris*) in known areas of population, Russian fur traders turned their attention to fur seals. The promyshleniki or hunters "soon began to surmise the existence of some islands in the north by observing the annual migration of the fur seals through the passes between certain of the islands—northward in the spring and southward in the autumn, when they were accompanied by their young" (Bancroft 1886:191). Owing to the dense fog characteristic of the Bering Sea in summer, the season for practical and comparatively safe exploration, many years elapsed before the discovery of St. George Island in 1786 and St. Paul Island in 1787 (Bancroft 1886:192–193). (According to legend, the discoverers, upon landing on St. Paul Island, found a pipe, a brass knife handle, charred remains of driftwood, and places where grass had been scorched.) Thus were the breeding grounds of the Pribilof fur seals exposed to commercial exploitation destined to create international controversy. The Commander Islands, Bering and Copper, had been discovered 45 years earlier in 1741 (Bancroft 1886:87).

Fur seals resorting to the Pribilof Islands were twice reduced to a fraction of their original number, the first time under Russian ownership and again during United States ownership of the islands. Imperfect and contradictory records suggest that 2.5 million seals plus an unknown number lost because of wastefulness and crude skin curing methods were killed during the period 1786–1867 (Sims 1906:33–34). Of wastefulness, Elliott (1884:147) translates from Veniaminov: "In 1803, 800,000 sealskins had accumulated, and it was impossible to make advantageous sale of so many skins; for in this great number so many were spoiled that it became necessary to cut or throw into the sea 700,000 pelts."

In a further translation from Veniaminov, Elliott (1884:140) also wrote that killing during the early years of Russian control was largely indiscriminate, without regard to sex, size, or number taken. Many rival companies tried to kill as many seals as possible. Consolidation of the firms into the Russian-American Company in 1805 partially slowed decline of the herd through better control of the kill. The new company declared a closed season in 1806 and 1807 and moved all island residents temporarily to Unalaska, apparently to prevent molestation of the seal herd. Sealing was resumed in 1808 on St. George Island and in 1810 on St. Paul Island.

Despite additional closures in the 1820's, destruction of the herd continued until 1834, when Russian overseers finally, or perhaps fully, recognized the dangers of overexploitation. From 1835 to 1867, the killing of male seals on land was restricted and the taking of females was forbidden (Osgood et al. 1915:21). (Island inhabitants told Elliott (1884:49) that females were not fully exempt from killing until beginning in 1847.) These measures allowed the herd to grow, during which time the take of surplus males increased proportionately. When Alaska was purchased by the United States in 1867, the herd was again sustaining an annual kill of several thousand male seals.

The intention of the U. S. Government

when it took over in 1868 was to maintain Russia's 33-year-old policy of sparing the females and allowing an adequate escapement of males for breeding. Sealing during the initial years 1868 and 1869 was, however, characterized by a ruthless slaughter exceeding even that during early Russian ownership of the islands. The kill during these 2 years has been reported by Osgood et al. (1915:21) at 329,000 and by the U. S. Department of Commerce (1906:32) at 225,901. Jordan (1898:26) reported the kill in 1868 as "not far from 300,000."

LEASE OF THE ALASKA COMMERCIAL COMPANY (1870–89)

In 1869, when the Pribilof Islands were set aside as a special reservation for protection of the fur seals, the U. S. Treasury Department was authorized to lease sealing privileges on land. The Alaska Commercial Company (ACC), a San Francisco firm which won the first of two 20-year contracts, began operating in mid-season of 1870. The lessee was bound by several rules and regulations in exchange for the right to take seals (U. S. Department of Commerce and Labor 1906:2–3). For example, the ACC was to pay the U. S. Government an annual rental fee of $55,000 and a tax of $2.62½ for each skin taken. Sealing was authorized only during the months of June, July, September, and October, and the ACC was not to kill any female seals or seals under 1 year of age. In addition to maintaining a school on each island, the ACC was to "furnish, free of charge, the inhabitants of the islands of St. Paul and St. George annually during said term 25,000 dried salmon, 60 cords fire-wood, a sufficient quantity of salt, and a sufficient number of barrels for preserving the necessary supply of meat." The ACC further agreed to kill not more than 75,000 seals on St. Paul Island and not more than 25,000 seals on St. George Island per annum. With a total annual quota of 100,000 in effect throughout the contract period (Table 1), the annual take of skins ranged from 71,884 to 99,408 during 19 complete sealing seasons (1871–89). Including 13,324 taken during a partial season in 1870, 1,782,035 seals were killed during the contract period (U. S. Treasury Department 1898:407). In addition, 95,618 pups and 99,684 young males were killed for native food. A total of 71,994 skins from these young males killed for native food was accepted for processing by the ACC, bringing the total of all skins shipped from the islands during the 20 contract years to 1,854,029. (The difference of 27,690 skins were rejected by the ACC as unfit for processing because of staginess, a term describing a fur seal in molt.)

Government officials responsible for allowing a kill of 100,000 male seals apparently believed that this number could safely be taken above the number needed for future breeding reserves, though the basis upon which their decision was founded is unknown. Dall (1870:496) wrote "it is probable that one hundred thousand might be safely killed." Because of his comprehensive "in residency" study of the natural history of the Pribilof fur seals, Elliott's (1884:62) belief that "100,000 male seals under the age of five years and over one, may be safely taken every year from the Pribilof Islands, . . ." could have been very influential in setting a maximum kill. (Though Elliott originally thought that the annual kill might be safely developed from 100,000 to 180,000, the possibility of saturating the fur market and harming the herd through the killing of too many fur seals caused him to fix the sustained annual kill at 100,000.) Elliott's study, however, did not begin until 2 years

Table 1. History of killing quotas and of seals marked for various purposes, Pribilof Islands, Alaska, 1870–1964.

Year	Annual Quota		Seals Marked			Marking Methods				
	Males	Females	Annual Number	Purpose	Age Classification	Branded	Sheared	Tagged	Ear Clipped	Flipper Check-marked
1870–71	100,000	NAK*	200	Homing instinct studies	Pup (♂–♀)				×	
1872–89	100,000	NAK	–	–	–					
1890–91	60,000	NAK	–	–	–					
1892–93	7,500	NAK	–	–	–					
1894	20,000	NAK	–	–	–					
1895	15,000	NAK	–	–	–					
1896	30,000	NAK	377	Devalue skins	Pup (♀)	×				
1897	20,000	NAK	7,251	Devalue skins	Pup (♀)	×				
1898	30,000	NAK	2,363†	Devalue skins	Pup (♀)	×				
1899	30,000	NAK	2,191†	Devalue skins	Pup (♀)	×				
1900	30,000	NAK	1,698†	Devalue skins	Pup (♀)	×				
1901	30,000	NAK	4,859	Devalue skins	Pup (♀)	×				
1902	30,000	NAK	2,742	Devalue skins	Pup (♀)	×				
1903	30,000	NAK	1,352‡	Devalue skins	Pup (♀)	×				
1904	15,000	NAK	2,054	Breeding reserve	2–4 years	×	×			
1905	15,000	NAK	2,174	Breeding reserve	2–4 years	×	×			
1906	15,000	NAK	2,238	Breeding reserve	2–4 years		×			
1907–09	15,000	NAK	2,000	Breeding reserve	2–3 years		×			
1910	none	NAK	1,271	Breeding reserve	2–5 years		×			
1911	none	NAK	1,000	Breeding reserve	3 years		×			
1912	none	NAK	2,005§	Breeding reserve	3 years		×			
1913–17	none	NAK	–	–	–					
1918–20	35,000	NAK	–	–	–					
1921–22	30,000	NAK	–	–	–					
1923	25,800	NAK	10,017	Breeding reserve	3 years	×	×			
1924	none	NAK	10,557‖	Breeding reserve	3–4 years		×		×¶	
1925	none	NAK	12,677#	Breeding reserve	3–5 years	×	×			

* No authorized kill.
† St. Paul only; no record kept of pups branded on St. George.
‡ St. George only; no record kept of pups branded on St. Paul.
§ Plus 5,229 pups branded for age–length studies.
‖ Plus 1,733 branded 4-year-olds from 1923 further marked by shearing in 1924.
¶ 1,000 only of 3-year-olds further marked by ear clipping.
# Plus 800 branded for unknown scientific studies and 1,525 branded 5-year-olds from 1923 further marked by shearing in 1925.

Table 1. *Continued.*

YEAR	ANNUAL QUOTA		SEALS MARKED			MARKING METHODS				
	Males	Females	Annual Number	Purpose	Age Classification	Branded	Sheared	Tagged	Ear Clipped	Flipper Checkmarked
1926	none	NAK	9,565	Breeding reserve	3 years		×			
1927	none	NAK	9,090**	Breeding reserve	3 years	×	×	×		
1928	none	NAK	8,852††	Breeding reserve	3 years	×	×			
1929	none	NAK	8,085††	Breeding reserve	3 years	×	×			
1930	none	NAK	6,539	Breeding reserve	3 years		×			
1931	none	NAK	5,226	Breeding reserve	3 years		×			
1932	none	NAK	3,009	Breeding reserve	3 years		×			
1933–39	none	NAK	–	–	–					
1940	none	NAK	5,000	Scientific	Pup (♂–♀)	×				
1941	none	NAK	10,000	Scientific	Pup (♂–♀)	×		×		
1942–44	none	NAK	–	–	–					
1945	none	NAK	973	Scientific	Pup (♂–♀)			×		
1946	none	NAK	–	–	–					
1947	none	NAK	19,183	Scientific	Pup (♂–♀)			×		×
1948	none	NAK	19,532	Scientific	Pup (♂–♀)			×		
1949	none	NAK	19,960	Scientific	Pup (♂–♀)			×		
1950	none	NAK	–	–	–					
1951	none	NAK	1,000‡‡	Scientific	Pup (♂–♀)			×	×	
1952	none	NAK	19,979	Scientific	Pup (♂–♀)			×		×
1953	none	NAK	10,388	Scientific	Pup (♂–♀)			×		×
1954	none	Kill all driven	10,000	Scientific	Pup (♂–♀)			×		×
1955	none	Kill all driven	49,870	Scientific	Pup (♂–♀)			×		×
1956	none	30,000	49,794	Scientific	Pup (♂–♀)			×		×
1957	none	50,000	49,842	Scientific	Pup (♂–♀)			×		×
1958	none	30,000	49,917	Scientific	Pup (♂–♀)			×		×
1959	none	50,000	49,881	Scientific	Pup (♂–♀)			×		×
1960	none	5,250	59,981	Scientific	Pup (♂–♀)			×		×
1961	none	43,750	49,921§§	Scientific	Pup (♂–♀)			×		×
1962	none	43,750	49,908‖‖	Scientific	Pup (♂–♀)			×		×
1963	none	43,750	46,890¶¶	Scientific	Pup (♂–♀)		×	×		×
1964	none	9,000 to 18,000	52,707##	Scientific	Pup (♂–♀)		×	×		×

** 200 sheared, branded, and tagged; remainder branded only.
†† 200 sheared and branded; remainder branded only.
‡‡ 100 tagged and ear clipped; remainder tagged only.
§§ Plus 740 seals selected and tagged as yearlings for survival studies and 737 pups and adults of all ages marked and tagged for behavior studies.
‖‖ Plus 801 seals selected and tagged as yearlings for survival studies and 589 pups and adults of all ages marked and tagged for behavior studies.
¶¶ 24,971 tagged and checkmarked; 21,919 sheared only. Plus 701 seals selected and tagged as yearlings for survival studies.
24,991 tagged and checkmarked; 27,716 sheared only.

after the contract was awarded to the ACC. His published findings, at least, had no bearing in licensing a kill of 100,000 per year.

A population estimate of over 4.5 million made by Elliott (1884:62) in 1872 and 1873, had it been true, would have indicated that a sustained annual kill of 100,000 male seals was not excessive. An area computation method of estimating the population was used by Elliott, who allowed an average of 2 square feet for the space occupied by every seal on the rookery, whether breeding bull, female, or pup. Assuming that the seals were uniformly distributed on the rookeries, this allowance, when applied to a computed 6,386,840 square feet of rookery space, yielded a rookery population (breeding adults and young) of 3,193,420. Nonbreeding animals were estimated at 1.5 million, bringing the total of all fur seals of the Pribilof herd in excess of 4.5 million. (Fur seals not participating in breeding activities on the rookeries are either at sea or are on hauling grounds, which are areas behind or adjacent to the rookeries where subadults and old, unproductive animals congregate.)

Investigators since Elliott's time sharply disagreed with the latter's methods and results. Jordan (1898:83) summarily dismissed the results of most of Elliott's work as little more than "an individual opinion greatly overdrawn by a too-vivid imagination." Hanna (1918:112) found from actual pup counts on 11 rookeries and counts of harems on all rookeries in 1917 that the density of the seals was not uniform, and that rookery seals each occupied an average of 6 square feet rather than 2, as maintained by Elliott. The rookery population in 1872–73, therefore, may actually have been no more than one-third of that estimated, or 1,064,473.

LEASE OF THE NORTHERN COMMERCIAL COMPANY (1890–1909)

When the ACC's lease expired in 1889, a new 20-year lease was awarded to the North American Commercial Company (NACC), a San Francisco firm organized especially for bidding on the contract. In obligations to the U. S. Government and to the Aleut people of the Pribilof Islands, features of the new lease were essentially those under which the ACC had operated. The cost to the NACC, however, was greater. For example, the annual rental fee was raised from $55,000 to $60,000 and the tax on each sealskin taken from $2.62½ to $9.62½ (North American Commercial Company 1891). The company's annual quota (Table 1), as fixed by the Secretary of the Treasury from 1890 to 1902 and by the Secretary of Commerce and Labor from 1903 to 1909, ranged from 7,500 to 60,000.

Unfortunately for the NACC, its contract period coincided with the heyday of pelagic sealing. Unlike the completely unregulated pelagic sealers, the NACC was restricted to an annual quota and to taking young males only. As a result, the company was able to secure only 342,651 skins by 1909, when its 20-year lease expired. According to Riley (1961:5–6), the pelagic sealers took at least 659,875 seals during the same period.

PELAGIC SEALING (1868–1911)

Pelagic sealing as a commercial enterprise began about 1868. By 1881, the increasing proficiency of a few engaged in the business attracted others, so that by 1889 many specially outfitted vessels were so employed. Over 600,000 seals were reported as taken on the high seas from 1889 to 1909, nearly twice the number taken on land during the same period. Many more seals were probably lost

through sinking or wounding and were not recorded as part of the pelagic take. Because most of the seals killed at sea were breeding females, the herd declined rapidly. By 1909, only about 200,000 seals remained.

In an effort to stop pelagic sealing, the United States claimed exclusive control over eastern Bering Sea and seized a number of sealing vessels there during the late 1880's. Because the vessels were mostly of Canadian registry, a controversy with Great Britain ensued. There followed a treaty (*modus vivendi*) concluded February 29, 1892, between the two countries and submission of the quarrel to the "Paris Tribunal of Arbitration." Principal regulations resulting in 1893 from this arbitration (1) prohibited pelagic sealing within 60 miles of the Pribilof Islands, (2) established a closed season for pelagic sealing from May 1 to July 31, and (3) forbade the use of nets, firearms, and explosives in taking fur seals within the Bering Sea (U. S. Congress, Senate 1895).

The regulations were ineffective. Nursing females habitually ranged farther than 60 miles from the Pribilof Islands in quest of food where they remained vulnerable to pelagic sealing. A closed season during May, June, and July allowed females to reach the islands and bear their young, only to be killed in August when at sea for food. Pelagic sealers successfully foiled the firearm restriction by employing skilled Indians using spears and canoes. The matter was further complicated by the appearance of Japanese pelagic sealers in the late 1890's. Because they were not obligated to abide by the regulations, the Japanese took seals up to and on land. Armed guards stationed on the major rookeries eventually prevented the Japanese from killing seals on land, though not until 1906 (Sims 1906:13–21).

Several schemes were devised in attempts to discourage pelagic sealing. Jordan and Clark (1899:325–338) conducted experiments in branding female adults and pups across the back in an effort to make their skins valueless. About 25,000 seals (mostly pups) were treated from 1896 to 1903 (Table 1), when the program was declared ineffective. On St. Paul Island, fences were constructed around various bodies of water in which young male seals were imprisoned briefly, preventing their escape to the sea and eventual destruction. In 1897, U. S. citizens were prohibited from engaging in pelagic sealing in the North Pacific Ocean and Bering Sea. These measures also had little effect on the pelagic sealing industry.

There were even proponents of a scheme to kill practically all seals appearing on the islands, thus putting pelagic sealers out of business. Critics of the plan pointed out, however, that once the herd regained a profitable level, the pelagic sealers would return.

Almost complete extermination of the herd by killing at sea did eventually bring the era of pelagic sealing to a close. Only then did the governments of Great Britain (for Canada), Japan, Russia, and the United States agree on terms which resulted in the North Pacific Fur Seal Convention of December 15, 1911 (U. S. Department of State 1928). The convention, which was to continue in force for 15 years from that date, prohibited pelagic sealing except by aboriginals using primitive methods. A sharing formula was established whereby Japan and Canada were each to receive 15 percent of the sealskins taken on the Russian-owned Commander Islands and 15 percent of those taken on the American-owned Pribilof Islands. Canada, Russia, and the United States each received 10 percent of the skins taken on the Japanese-owned Robben Island. The convention also provided that, at the ex-

piration of 14 years or at any time thereafter, 12 months written notice given by one or more parties to all the others could cause termination of the convention. The Japanese government exercised this right on October 23, 1940. From October, 1941, until the four nations were again brought together under a new convention in 1957, the United States and Canada maintained a provisional agreement in which the latter country continued to share in the Pribilof fur seal harvest in return for her continued abstinence from pelagic sealing.

THE PERIOD OF HERD GROWTH (1911–40)

For nearly half a century before 1911, frequent reference was made to the killing of special age-classes of seals when, in truth, the age of no seal beyond its first year was absolutely known. Probably the market for skins from 3- and 4-year-old fur seals developed both as the result of availability and because of the better fur value of young animals. Bryant (1890) relates the following values for various ages of males as determined by an Alaska Commercial Company agent sent to London to examine the skins as they were classified for the market: age 2, $15; age 3, $16 or $19; age 4, $16; and age 5, $2.50. These observations caused ACC officials to be more selective and "to take as many three-year-old seals as possible, making out the one-hundred thousand from those two or four years old." As a result, the value of the annual catch trebled at once. In turn, this fact caused the tax on each sealskin taken to be raised from $2.62½ as paid by the ACC, to $9.62½, as paid by the NACC.

That early kills were composed chiefly of males in ages 2 through 5 was undoubtedly as true then as it is today. Current research supports some of the early assumptions as to age and refutes others. For example, 3- and 4-year-olds have made up over 89 percent of the annual kill of males since 1954 (Roppel, Johnson, Anas, and Chapman 1965:5), not strictly because of selection, but because seals of these ages are dominant among the animals available in July. Also, yearling seals are now known to come ashore in late September and October (Roppel, Johnson, and Chapman 1965:18) rather than in July as once believed (U. S. Congress, House 1911: 20). Most seals formerly considered to be yearlings undoubtedly were 2-year-olds.

From time to time, various experiments were conducted for reasons other than that of determining age. The ears of 400 pups on St. Paul Island were clipped in 1870 and 1871 (U. S. Treasury Department 1898:29, 38, 41, and 42) to provide a basis for testing a conviction of resident Aleuts that fur seals invariably return to the island and area (rookery–hauling ground complex) of birth beginning in the second year of life. The information was needed by management agents to ascertain the necessity of proportioning the kill among the several rookery–hauling ground complexes rather than yield to the tendency to fulfill quotas mostly from those adjacent to the village. Though recoveries of marked animals 2 and 3 years later indicated that straying was considerable, agents decided that killing should be done on all areas. Recent research has shown that straying is most common among young males, but that the tendency decreases with age in both sexes (Roppel, Johnson, Bauer, Chapman, and Wilke 1963:35).

Hot-iron branding from 1896 to 1903, done to discourage pelagic sealing, provided incidental information on longevity of females. Thus, investigators learned in 1922 that some females live to age 19 (U. S. Department of Commerce 1923: 114). Table 1 shows the number of seals marked for various purposes since 1870.

Use of body size as an indication of age eventually led to the branding of 5,229 pups in 1912 (U. S. Department of Commerce 1913:95) for the specific purpose of relating age to length. With some variation, age–length standards (Table 2) subsequently developed (U. S. Department of Commerce 1919:96) were used by management to classify kills during the years 1918–61, inclusive. The relationships thus established were useful in that they provided, for the first time, information on the relative number of seals of each age-class taken in the kill. Officials recognized, however, that there was an overlapping of lengths of any three consecutive age-classes. Roppel, Johnson, and Chapman (1965:52) demonstrated considerable overlapping in 1963 by measuring 1,005 3-year-old males tagged as pups in 1960. Twenty-nine percent would have been classified as 4-year-olds according to the age–length standards established in 1918.

In 1950, a much more precise method of determining the ages of seals was developed by Scheffer (1950:309–311), who discovered that the roots of canine teeth exhibit annual growth layers comparable to those found in trees. Examination of teeth from seals tagged as pups and recovered in subsequent years showed that this method was 90 percent accurate up to age 7. Thus, survival of individual year classes since 1951 has been traced. From 1951 to 1955, right upper canine teeth from 5 percent of the males killed were collected, cleaned, and read for age each day. The age composition of the daily sample was then projected to the corresponding kill. Since 1956, teeth from 10 percent or more of the males and over 20 percent of the females killed have been included in the sample. A sample of any desired size is easily extracted from the kill because the animals are arranged in rows of 10 seals for skinning. For example, a 10 percent sample is collected by taking the canine tooth from the seal in position number 1 in the first row, in position number 2 in the second row—continuing progressively throughout the kill. In this manner, the tooth collector works his way back and forth through the seal kill (Abegglen et al. 1957:35).

Table 2. Age–length relationship of fur seals, Pribilof Islands, Alaska, 1918.

AGE	LENGTH (INCHES)
Yearlings	up to 36.75
2	37–40.75
3	41–45.75
4	46–51.75
5	52–57.75
6	58–63.75

Up to 1904, the lessees were restricted in taking seals only by an annual quota. Virtually every male seal appearing on the hauling grounds was killed. The first real attempt to control the kill of seals on land came in 1904 when a decision was made to (1) spare all 4-year-old males, (2) mark and reserve 1,000 each of 2- and 3-year-old male seals annually for breeding purposes, and (3) limit the size of fresh skins to those weighing 5½ pounds or more; in 1906, this limit was reduced to 5 pounds and a maximum limit of 8½ pounds was imposed (U. S. Congress, House 1911:36, 44, and 235). Minimum and maximum skin weights were intended to restrict the kill to 3-year-olds. The marked breeding reserves reinforced the sparing of 4-year-olds as a guarantee of future breeding stock.

Male seals to be spared for breeding purposes were marked by hot-iron branding on the head, neck, or back, by shearing a patch of fur from the top of the head, or by both. Over 100,000 were treated from 1904 to 1932 (Table 1), when the system was abandoned in favor of general field observations for assurance that sufficient males were being saved (U. S. Congress,

House 1911, U. S. Department of Commerce 1912–32).

From 1910 to August 24, 1912, the quota system was replaced with instructions to kill the normal yield of the herd. Skin weight restrictions and the marking of breeding reserves were continued as regulatory measures. An act of Congress approved August 24, 1912, prohibited commercial killing of fur seals until August 24, 1917, during which period approximately 22,000 were taken for food for the island residents and at least 25,000 unmarked 3-year-old males were said to have been reserved for future breeding stock (U. S. Department of Commerce 1913–18). Though the skins were marketed, skin weight restrictions were not used during these food killings. Seals were taken in all months of the year except February, but most were killed in June, July, August, October, and November. A history of male killing on the Pribilof Islands is given in Fig. 2 by 5-year intervals from 1911 to 1964.

Commercial sealing was resumed August 25, 1917; 1,943 males were taken by December 31 of that year. Body length was, in effect, used to control the kill beginning in 1918, though island agents were instructed to kill by age. Sealing began January 14 in that year, ending December 12 with a kill of 34,890. The reserving of 5,000 3-year-olds in 1918 and of unreported numbers from 1919 through 1922 apparently was accomplished partly by field observations and partly by instructions to kill specified numbers of seals of various ages. Age compositions of quotas authorized for the years 1918–22 follow:

Year	Total Quota	Age				
		3	4	5	6 and Older	7 and Older
1918	35,000	35,000				
1919	35,000	15,000	2,000	1,000	17,000	
1920	35,000	18,730	5,500			10,770
1921	30,000	25,850	3,450	700		
1922	30,000	30,000				

The authorization to kill large numbers of relatively old males in 1919 and 1920 resulted from a belief that the 5-year closed period of 1912–17 was too restrictive, and that the skins of these seals could be successfully processed for the fur market. Officials, who estimated that 60,000 additional males could have been taken during the closed period without slowing recovery of the herd, based their belief on observations of a large surplus accumulated on the rookery fringes and hauling grounds as *idle bulls* (adult males without harems). Although the kill totaled only 7,731 age 6 and older in 1919 and 722 age 7 and older in 1920, these same officials believed that the herd benefited from reduced fighting among the males (U. S. Department of Commerce 1920–21).

The quota was reduced to an authorized kill of 25,800 3-year-olds in 1923. Also, a second series of marking young males for future breeding stock was started when 5,012 3-year-olds were branded and sheared and 5,005 were sheared only. From 1924 to 1932, the last year in which breeding reserves were marked, island agents were instructed to take all 3-year-old males available to about July 31.

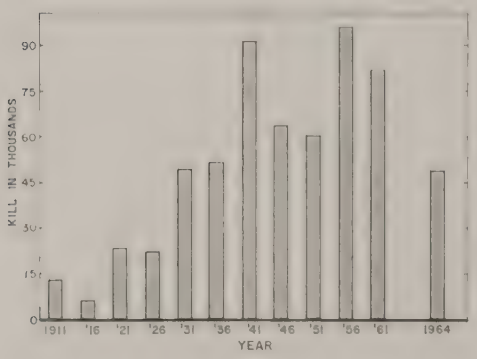

Fig. 2. Male seal kill, Pribilof Islands, Alaska, 1911–64.

The annual kill fluctuated between 15,000 and 31,000 of all ages from 1919 to 1928, and from 1929 to 1940, between 40,000 and 65,000 (U. S. Department of Commerce 1920–38, U. S. Department of Interior 1941–42). The seals killed during these years were selected by age, though, in reality, this meant selection by body length. Island agents were not actually instructed to kill by length until some years later.

THE POPULATION PLATEAU (1940–55)

The growth rate of the herd after 1911 was traced from complete counts of live pups made annually from 1912 to 1916 (U. S. Department of Commerce 1917:91) and from partial counts made from 1917 to 1922 and in 1924 (U. S. Department of Commerce 1918–23 and 1925). Growth of the herd prevented even partial counts of live pups after 1924. Use of an estimated annual increase of 8 percent developed from the counts, however, allowed a satisfactory computation of herd size and forecast of the kill from 1925 to 1933. In 1942, the rate of increase was arbitrarily reduced to 7 percent and, in 1947, to 6 percent (U. S. Department of Interior 1950:75). The system was discontinued in 1948 as unrealistic, because the kill no longer increased at the rate of growth calculated for the herd. Only the counts of harem and idle bulls begun in 1911 were continued.

On October 23, 1940, Japan announced her intention to abrogate the fur seal treaty of 1911. She claimed that stragglers from the American seal herd were damaging her offshore fisheries. Studies of fur seal population dynamics, migration routes, and food habits were renewed in 1940 and, in September, 5,000 seal pups of both sexes were branded, the first animals marked for scientific purposes since 1929 (Table 1).

Partly to placate Japan and partly to prevent an increase in the number of idle bulls, the harvest was increased in 1941. In a season extended to August 8 from the usual late July termination, 92,802 young males were taken. Because the extended season included part of the natural hauling-out (coming onto land) period of young females, 2,211, or 10 times the usual number of females, were accidentally killed. Also, 10,000 seal pups were successfully branded and tagged in 1941 (U. S. Department of Interior 1943:53).

Wartime evacuation of the people to southeastern Alaska from the Pribilof Islands on June 16, 1942, prevented a normal harvest (150 were killed) of fur seals, though a special effort was made in 1943 to recoup the loss by killing 4-year-olds in addition to the normally authorized kill of 3-year-olds. A special sealing crew of Pribilof Aleuts returned to the islands in 1943 took 116,407 males and 757 females between June 8 and August 9 (U. S. Department of Interior 1944:51–52). This was the greatest number of males killed on the islands in a controlled situation. At this time, 364 branded skins were taken, marked, and processed for pelage studies.

In 1944, all Pribilof Aleuts evacuated in 1942 were returned, and 47,652 seals were taken between June 10 and July 31 under a kill restricted to 3-year-olds by minimum and maximum lengths. Managers were puzzled because the kill was low. Seals of ages 3 and 4 are now known to overlap considerably in length, and that by extending the season and the length of seals killed, many of both these ages were taken in 1943 that would not normally have been killed until 1944.

From 1945 through 1955, 59,000–77,000 males were killed annually. New financial support was provided in 1948 for tagging pups, making photographic surveys, and for conducting other studies. Additional

information gained as a result of these and subsequent studies refuted some long-held beliefs. It was learned, for example, that all females did not give birth to a pup every year (Abegglen and Roppel 1959:77), that pup mortality rates were much higher than the 1–2 percent factor used for years, that a large reserve of breeding-age males (idle bulls) was not necessary, and that females rarely bred at age 2 and only occasionally at age 3 (Abegglen and Roppel 1959:76–77). It was also discovered that year-class survival and the return of 3-year-olds was highly variable, and that body length was only roughly related to true age. Most important was the probability that highly variable survival of fur seals was due to a high population.

In 1954 and 1955, all females (approximately 1,000) that appeared in the drives were taken. These animals provided data for research and served as a guide to the feasibility of either-sex harvests.

By 1955, the number of idle bulls counted on land nearly equaled the number of harem bulls (Abegglen et al. 1959: 131). Persistent use of relatively low maximum length limits to govern the kill of young males has been the major cause of substantial increases in the number of idle bulls. Many 4-year-olds and a good proportion of the 3-year-olds have been longer than the prescribed limits. The traditional practice of ending the kill about July 31 has also helped to increase the number of idle bulls by allowing a certain number of late arrivals to escape the kill and become too large for killing the following year.

Thus passed a period (1940–55) important in recent evolution of fur seal management. Increased mortality of the young and wide fluctuations in survival as by-products of a peak population became accepted facts to those closely allied with wildlife biology, but to those not familiar with wild animal populations, the period was one of changing ideas, viewed with skepticism.

THE PERIOD OF HERD REDUCTION (1956–64)

Herd reduction to improve rearing success of young animals and maintain total productivity with a smaller breeding stock had many proponents and was backed by the results of population studies of other species of wildlife. Fur seals of the Pribilof Islands seemed to be ideal subjects on which to test the effects of herd reduction because the population had reached a peak about 1940 and only a fraction of the young of recent year classes was estimated to live to age 3. In addition, the ability to accurately distinguish ages through tooth ridge counts revealed that extreme fluctuations in survival of the young were occurring. Plans were therefore made to reduce the number of breeding-age (4 and older) females from an estimated 1,200,000 to about 800,000. The reduction was expected to stabilize production of pups at about 500,000 and to lower mortality and reduce or eliminate wide fluctuations in the survival of young seals. A smaller population was furthermore expected to produce a sustained annual yield of 60,000 males and 30,000 females above the number needed for perpetuation of the herd.

A kill of 22,680 females of all ages in 1956 marked the beginning of the herd reduction program. Natural mortality coupled with a commercial kill of 270,054 females through 1963 apparently has reduced the female population to or near the originally calculated level (800,000) of optimum yield, though uncertainties about this conclusion still exist. Also, recently revised calculations suggest that the sustained annual yield of females may lie within a range of from 9,000 to 18,000

rather than 30,000 as originally proposed. Accordingly, the kill of 43,860 females in 1963 was the last for the purpose of herd reduction, and 16,452 were taken in 1964 as surplus to needs of the herd. Apart from reducing the population of breeding females, the herd reduction program was also beneficial in eliminating a large number of old and unproductive females.

Beginning in 1956 also, the traditional practice of terminating the male kill on or about July 31 was ended, and young males were taken to August 15 to prevent further increases in the already excessive numbers of idle bulls. The unusually large kill of 95,734 males in that year was due partly to the extended season, but mostly because of excellent survival of two consecutive year classes, 1952 and 1953. Survival of year classes has ranged from very poor to excellent. For example, 83,120 males from the 1952 year class were taken subsequently in the commercial kill while the 1956 year class yielded scarcely 18,000. In addition, pup mortality on land has ranged from 25,042 to 119,505 since 1953 (Table 3).

Since 1956, the male kill has begun from June 27 to July 2 and continued to various dates between July 31 and August 15, depending on the number of males available. An average of 48,000 males were taken annually during the 9-year period, with a range of from 30,195 in 1959 to 95,734 in 1956.

As part of the new management policy, the relation of fur quality to age, sex, and time of season when the seals are taken was studied. Examination of skins from known-age (tagged as pups) males and females taken in the kill showed that young animals began to molt and grow new fur earlier than old seals, and that the condition first appeared in late August. Skins having short new guard hairs emerging in the fur are described by sealers as *stagey*.

Table 3. Dead-pup counts, Pribilof Islands, Alaska, 1953–64.

YEAR	ISLAND		TOTAL
	St. Paul	St. George	
1953	82,123	9,101	91,224
1954	100,987	10,139	111,126
1955	79,321	Not counted	79,321
1956	103,642	15,863	119,505
1957	64,745	9,769	74,514
1958	32,746	4,994	37,740
1959	41,962	7,284	49,246
1960	65,774	8,928	74,702
1961	60,760	10,251	71,011
1962	47,531	6,217	53,748
1963	34,228	5,011	39,239
1964	22,651	2,391	25,042

Males became stagey before females. By mid-September, many skins of both sexes had lost their commercial value. In addition to studies pinpointing the onset of staginess, several hundred skins from known-age 2- to 10-year-old females were collected, marked for identification, and processed into finished furs. Grade and size of the finished skins were then compared according to the body length, age, and reproductive condition of each animal. The percentage of prime, unblemished skins decreased as larger (and older) animals were included in the sample. Among females of known reproductive condition, the skins of younger, nonpregnant females graded higher. The effect, however, of pregnancy on the value of skins from a given age-class could not be determined from the samples. Results of the processing and sale of the female skins have been described by Scheffer and Johnson (1962).

New management techniques have been adopted and others discarded since 1956. For example, large seals rejected on the killing field each day were once counted as breeding reserves, and small seals were considered an index to the crop the following year. Because the hauling grounds were driven repeatedly and because the same seals were picked up several times,

the techniques were abandoned in 1960 as inaccurate. Marking rejected seals to insure adequate escapement had previously proved impractical.

Since 1961, the color of vibrissae or whiskers has been used as a guide for separating females by age on the killing fields. Because of their apparently superior quality, skins from 2- to 5-year-old females are barreled separately and processed differently from older females. In general, females age 4 and younger have black vibrissae, 5- and 6-year-old females have a mixture of black and white vibrissae, and those 7 and older have white vibrissae.

In 1962, the practice of roughly measuring each male seal was eliminated, and age classification of the kill from tooth samples was adopted. The latter technique of determining age greatly reduced the element of error that resulted from using body length as a measure of age. Body-length limits of about 42–48¾ inches (tip of nose to tip of tail) are now used only as a guide in killing in years when a substantial escapement of males is needed for future breeding stock. In years when there is no need to replenish breeding stock, the maximum length limit will be abandoned and most males above 42 inches in length that are not developing a mane will be killed. Some 5-year-olds and most 6-year-olds have a developing mane (a secondary sex characteristic) composed of long, silver-tipped guard hairs on the neck and shoulders.

The effects of herd reduction are being traced on land through a number of techniques that contribute to the overall study of population dynamics. These include (1) pup tagging as a basis for estimating the number of pups born through tag recoveries principally at ages 3 and 4; seals that have lost their tags are identified as to year class from a checkmark applied to the flipper at the time of tagging; (2) pup marking and sampling for estimating the number of pups born in the summer of birth; (3) annual counts of adult males and dead pups; (4) age classification of commercially killed seals; (5) studies of reproduction; and (6) mortality studies. Pathology, bacteriology, parasitology, nutritional requirements of pups, and anatomy and physiology of the fur seal are emphasized in acquiring an understanding of mortality.

At sea, studies of reproduction, migration routes, distribution, food habits, and intermingling of fur seals from the various breeding grounds are being made.

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Received for publication June 11, 1964.

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p. 30

MAINTENANCE OF OYSTER TISSUE *IN VITRO*. Aaron Rosenfield, Bureau of Commercial Fisheries Biological Laboratory, Oxford, Maryland.

(Abstract)

Tissue culture has had recent wide application in studies of diseases in vertebrates and would have comparable utility in studies of certain aspects of disease in economic molluscs such as the American oyster. An oyster tissue culture system could be used for (1) the detection of viruses, (2) a study of cytopathologic effects of micropathogens, and (3) growth of cryptic life-cycle stages of microparasites suspected of causing mass mortalities of oysters. Some progress has been made in the development of such a system.

Vertebrate tissue culture media, with adjusted salt concentrations, were screened for their ability to support the maintenance, and possibly the growth, of oyster tissues and cells. Explants of oyster venticle (approx. 1 to 2 mm^2) were introduced into Leighton tubes and Maximow slides with and without plasma clots and incubated at 20°C in appropriate media. Media containing 10% oyster serum plus 100 units penicillin and 100μg streptomycin/ml were changed weekly for the first 4 weeks and monthly thereafter. In experiments with plasma clots, several cell types were seen to migrate from the explant within 1 to 2 hours after planting. Within 2 weeks strand-like aggregations of cells had emanated from the periphery of the explants that had become attached to the glass. Pulsations of heart explants were observed up to 10½ months after planting in modified Eagle HeLa, L.Y., and Puck's N16 media. Cell division was not observed. In experiments without plasma clots, modified MME (Minimal Medium, Eagle), 858, Eagle L, and Scherer's media, in addition to the media already mentioned, supported maintenance of pulsations up to 5 months, although explants did not adhere to the glass. No strand-like "outgrowths" were observed, however, in these maintenance cultures. Efforts to induce cell division in explant heart cultures by the addition of the water-soluble fraction of oyster embryo extracts and with phytohemagglutinin were not successful.

The knowledge that it is possible to maintain oyster tissue *in vitro* for prolonged periods has permitted us to undertake other tissue culture studies. Maintenance cultures as described can be used in studies of oyster diseases.

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pp. 8–9

STARCH-GEL ELECTROPHORESIS OF OYSTER SERUM. Aaron Rosenfield and Carl J. Sindermann, Bureau of Commercial Fisheries Biological Laboratory, Oxford, Maryland.

(Abstract)

Electrophoretic methods are becoming widely used in the study of plant and animal systematics. The methods appear particularly useful for detecting variations that are not readily distinguishable morphologically. In our laboratory, protein components in oyster serum and body fluid were compared in efforts to characterize populations, species, and genera within the family Ostreidae. Analyses of some multiple-enzyme systems (isozymes) in adult serum were made by vertical starch-gel electrophoresis. Dehydrogenases, peptidase, oxidase, phosphatases, and esterases were found in oyster serum; however, only those patterns that enabled differentiation among the taxa are discussed here. The oyster groups used were: *Ostrea edulis* (from Boothbay Harbor, Me.), *Ostrea lurida* (from Hood Canal, Wash.), *Crassostrea gigas* (from Hood Canal, Wash.), *Crassostrea virginica* (from Malpeque Bay, P.E.I., Canada; Chesapeake Bay, Md.; Chincoteague Bay, Va.; and Apalachicola Bay, Fla.).

Genera can be distinguished on the basis of patterns of general protein serum components as visualized by Amido-Schwartz or Ponceau S, as well as by patterns of such isozymes as alkaline phosphatase, esterase, amino peptidase, cytochrome oxidase, and glutamic dehydrogenase. Differences between *C. gigas* and *C. virginica* were apparent in zymograms of amino peptidase, esterase, and glutamic dehydrogenase. Differences between *O. edulis* and *O. lurida* were apparent in the isozyme patterns for glutamic dehydrogenase. The zymograms of glutamic dehydrogenase permitted separation of different populations of *C. virginica*. One component was found in the population of *C. virginica* from Apalachicola Bay, Florida, that was not present in the other populations. Also, slight differences were noted in populations from Malpeque Bay, Canada.

Although at present no functional significance is attached to the components visible in the zymogram patterns—particularly those of glutamic

dehydrogenases—the methods thus far have enabled us to differentiate among some genera, species, and geographic populations of oysters. Further experiments are in progress with other enzyme systems and species of shellfish in efforts to detect enzyme changes that accompany growth, development, and pathological conditions.

"SOME USES OF STATISTICS IN FISHERY BIOLOGY"

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Proceedings [of the Interdisciplinary Conference on] Mathematics, Agent of Change in the Biological Sciences, Physical Sciences, Social Sciences, and the Humanities, College of General Studies, University of Hawaii, April 20-21, 1965.

Introduction

To some extent fishery biology can be considered as the study of the interaction of units of fishing gear with harvested populations of fish. Many of the advances in the study of this interaction have been accomplished through the investigation of models of populations. Parameters of these models include natural mortality, fishing mortality, growth, and recruitment. It is almost impossible to obtain these parameters directly; they must be estimated from samples. The estimation of parameters from samples is a part of the study of statistics.

Statistics has been an important agent of change in fishery biology. Its applications in this field utilize sampling theory, estimation of parameters, tests of hypotheses, and stochastic models. In the present paper, three small segments of rather well-known statistical theory are presented as applications in fishery biology. The first application considers the use of linear statistical models for catch predictions. In the second, some concepts of multivariate statistical theory are mentioned; in particular, attention is drawn to the analogy between the univariate "t" test and the multivariate "T^2" test. Finally a new concept for the use of discriminant-function analysis in fisheries is discussed.

Catch Predictions

Studies of catch prediction are among the most challenging in fishery science. The utility of a catch prediction can be measured by the width of a confidence interval about a predicted value of the catch relative to the magnitude of the catch. If the ratio of the magnitude of the catch to the confidence interval is large, then the prediction is useful. In general, confidence intervals can be reduced by increasing sample size and the reduction reflects an increase in the utility of the prediction. In catch predictions, however, this reduction in confidence-interval width with realistic increases (usually only one sample point can be acquired for each year) in sample size may be inconsequential. Our consideration of a confidence interval about a catch prediction is limited to a special case of the general linear hypothesis model (see Graybill, 1961, p. 106-148) in which the prediction estimate is based on the linear regression of catch on a single independent variable (usually a feature of the environment).

The width of a confidence interval about a mean (based on normal approximations) is obtained from the product of the standard deviation of the mean and a value from the t distribution for a given probability level and degrees of freedom. In linear regression the random or unexplained component e, used to derive the confidence interval about an average or expected value of y for a given x, is

$$e = (\hat{\beta}_1 - \beta_1) + (\hat{\beta}_2 x - \beta_2 x), \qquad 1$$

where β_1 and β_2 are parameters, $\hat{\beta}_1$ and $\hat{\beta}_2$ are estimates of parameters and x is a value of the independent variable. Note that e is the difference between the parameters and their estimates. It is well known that one-half this interval is

$$t_\alpha \hat{\sigma}_{y.x} \sqrt{\frac{1}{n} + \frac{(X_o - \bar{x})^2}{\Sigma(x_i - \bar{x})^2}} \quad , \qquad (2)$$

where t_α s a value from the t distribution with (n-2) degrees of freedom at the α probability level, $\hat{\sigma}_{y \cdot x}$ is the estimated standard deviation of the dependent variable for fixed x, and X_o is a specified value of X for which the confidence interval on catch is to be constructed.

By contrast, in the problem where the prediction of a single future value is desired, the random or unexplained component e' is given by

$$e' = Y - \hat{\beta}_1 - \hat{\beta}_2 x, \qquad (3)$$

where x is a specified value of the independent variable and Y is the predicted value. Note, that here e' is the difference between a linear combination of the parameters and the predicted values. One-half the confidence interval associated with (3) is

$$t_\alpha \hat{\sigma}_{y.x} \sqrt{1 + \frac{1}{n} + \frac{(X_o - \bar{x})^2}{\Sigma(x_i - \bar{x})^2}} \qquad (4)$$

As a simplification, consider the minimum possible width of the confidence intervals with fixed variance and sample size. This value is obtained when $x_o = \bar{x}$, eliminating the last term under the radicals. In the more usual case, where prediction is not desired, formula (2) is appropriate. It may be noted that the confidence interval described by (2) can be made arbitrarily small by increasing sample size. If prediction is desired, formula (4) is appropriate; here, however, the width of the confidence interval cannot be made arbitrarily small as

sample size increases but approaches a limit, $2t_{\alpha}\hat{\sigma}_{y.x}$. In fact, for the point $x_0 = \bar{x}$, the width of the confidence interval can never be less than $2t_{\alpha}\hat{\sigma}_{y.x}$, regardless of sample size.

A ready approximation of the quantity $2t_{\alpha}\hat{\sigma}_{y.x}$ is obtained by noting that $t_{.05} \cong 2$ and that $4\hat{\sigma}_{y.x}$ is approximately equal to the range about the regression line. Therefore, the minimum width of a prediction interval about a regression line is roughly equivalent to this range.

Catch predictions, then, provide information to the fishing industry, a logical framework within which to develop new knowledge, and a basis for inferences that could explain phenomena which underlie changes in availability and abundance of fishes. The utility of each of these applications is enhanced by the narrowness of the prediction interval. This utility, for the previously described model, can be measured in terms of the degree to which the regression accounts for the total variability of the data, or in other words, the ratio of the range about the regression line to the total range must be small. This situation may be difficult to attain under natural conditions. An increase in sample size (usually the number of years in annual catch predictions) is initially helpful in reducing a prediction interval, but ultimately it is not the number of sample points, but the inherent variability of the catch relative to the independent variable, that determines the utility of the prediction.

The relative merit of predictions with equivalent confidence intervals should also be considered. One criterion of merit is the explanatory power of a prediction. Explanatory power is a qualitative measure of the degree to which a prediction accounts for the mechanisms which generate a considered phenomenon. For example, it is easy to predict "the next year's catch" by using the average value of catch for the preceding several years. Such a prediction may be surprisingly accurate but is clearly low in explanatory power; the deviations from the predicted value are all pooled as an unknown term. By contrast, predictions which attempt to account for the underlying mechanisms which alter year-class strength (for example) have high explanatory power. Suppose then that two predictions are available for a certain fishery, both giving approximately equal confidence intervals: one is based on catch in preceding years; the other attempts to account for catch on the basis of some mechanism such as currents or year-class strength. The latter prediction would be favored because of its greater explanatory power. It is interesting that predictions of low explanatory power are easier to forward than those with high explanatory power. Equivalent prediction intervals may not exist beyond a conceptual framework and the widths of prediction intervals may have to be sacrificed for increases in explanatory power.

A further problem concerning confidence intervals arises from the use of a linear model with a single independent variable. It seems unlikely that the simplicity of this model is attained with great frequency among phenomena that might be useful for prediction. Indeed, Ricker (1962, p. 191-192), after reviewing enigmatic features of the

biology of the intensively studied pink salmon (Oncorhynchus gorbuscha), concluded by emphasizing the need for a consideration of multiple causation. But the use of more complex models for prediction is made difficult by the relatively few degrees of freedom that are available in these problems because additional in degrees of freedom are lost when more complex models are constructed. Where the initial degrees of freedom are few, substantial increases in the width of the confidence interval may ensue, particularly when the inherent variability of the data is large.

Further discussion of the difficulties inherent in using some of the presently available data for prediction is given by Gulland (1964). That some of these difficulties may be real is shown by a comparison of the papers of Carruthers et al. (1951), Gulland (1953), and Saville (1959).

Multivariate Analogues

Regression and correlation analyses are widely applied in fishery biology. Multivariate analogues to univariate statistical methods, however, are not generally used (actually univariate analysis of variance is a special case of the more general multivariate theory). These multivariate analogues are especially useful when measurements of the several variates are correlated.

Since so little use is made of these procedures in fisheries it seems worthwhile to outline the analogy between Student's t and its multivariate analogue Hotelling's T^2 (see Anderson, 1958). In the univariate case the sample mean is

$$\bar{x} = \frac{1}{n} \sum_{i}^{n} x_i \qquad 5$$

In the multivariate case the sample mean on p-variates is given by the vector

$$\underline{\bar{x}} = \begin{bmatrix} \frac{1}{n} \sum_{j}^{n} x_{1j} \\ \frac{1}{n} \sum_{j}^{n} x_{2j} \\ \vdots \\ \frac{1}{n} \sum_{j}^{n} x_{pj} \end{bmatrix} = \begin{bmatrix} \bar{x}_1 \\ \bar{x}_2 \\ \vdots \\ \bar{x}_p \end{bmatrix}, \qquad 6$$

where an underlined symbol denotes a vector.

In the univariate case the variance is given by

$$s^2 = \frac{\sum_i (x_i - \bar{x})^2}{n-1} \qquad 7$$

and in the multivariate case the "variance" is an array of variances and covariances among the variates, viz.,

$$S = \begin{bmatrix} s_{11} & s_{12} & \cdots & s_{1p} \\ s_{21} & s_{22} & \cdots & s_{2p} \\ \vdots & \vdots & & \vdots \\ s_{p1} & s_{p2} & \cdots & s_{pp} \end{bmatrix} \qquad 8$$

where the capital letter refers to a matrix and s_{ij} is the variance of the i-th variate when i = j and the covariance of the i, j variates when $i \neq j$.

It is sometimes useful to divide the elements of S by $\sqrt{s_{ii}s_{jj}}$ yielding a matrix of correlation coefficients for the considered variates,

$$R = \begin{bmatrix} 1 & r_{12} & \cdots & r_{1p} \\ r_{21} & 1 & \cdots & r_{2p} \\ \vdots & \vdots & & \vdots \\ r_{p1} & r_{p2} & \cdots & 1 \end{bmatrix} \qquad 9$$

We can note that the univariate t-test statistic is given by

$$t = \frac{\bar{x} - \mu}{\frac{s}{\sqrt{n}}}$$

$$= \sqrt{n}\,(\bar{x}-\mu)s^{-1}$$

10

Squaring both sides we have

$$t^2 = n(\bar{x}-\mu)\,(s^{-1})^2(\bar{x}-\mu)$$

11

which now has the form of its multivariate analogue, Hotelling's T^2 statistic,

$$T^2 = (\underline{\bar{x}} - \underline{\mu})'S^{-1}(\underline{\bar{x}}-\underline{\mu})$$

12

where the prime indicates the transpose of the vector, and the negative exponent denotes the inverse of the variance-covariance matrix.

These multivariate techniques can be applied both for estimation and testing hypotheses and are especially important in studies of multiple causation, where the effects of correlation among the variables may, over certain ranges, be more important than the absolute values of the variables.

Discriminant Functions

Still little used, but somewhat more frequently than multivariate analyses, is classification theory in the form of discriminant function analyses. This analysis was used by Stone (1947) to investigate meristic variation in darters. A résumé of the problem is given by Hill (1959), who studied meristic variation in American shad (Alosa sapidissima). Fischler (1959) applied Hill's results in an analysis of the racial structure of shad taken in the commercial catches of the middle Atlantic Bight.

Another possible application of discriminant function analysis, the determination of age in fish, was discussed by Rothschild (1962). Here the ages of fish are determined by counting annuli on scales or other hard parts. The assigned age of a fish determined by scale reading, however, is not necessarily its true age. Experienced scale readers disagree on assigned age for the same fish (Clark, 1958) and on the age of the same fish determined by different methods (Kohler and Clark, 1958). Even if several technicians agree on assigned age, there is no guarantee that assigned age is the true age; assigned age is a chance variable. When fish of known age are not available, error between assigned age and actual age cannot be assessed.

Assessment of error between assigned age and true age must utilize samples of fish of known age. Let us suppose that we obtain samples of fish of known age from the considered population. An assumption is that increases in age are accompanied by an increase at different rates of certain morphometric measurements (e.g. total length, head length). Then 1-year-old fish from a given population will be characterized by a set of morphometric measurements which differ, on the average, from sets of similar measurements on 2-year-old fish from the same population. Morphometric measurements from a single fish form a vector of observations. A fish of unknown age may be described by a vector of observations and this vector is classified as being closest to one of the known-age vectors: that known-age mean vector which is closest to the observational vector gives the estimated age of the fish. The classification of fish of unknown age into estimated age by means of discriminant functions is only practical for two or three statistical populations of age groups. All age groups should have mean vectors which are multivariate normal approximations within each age group and a common variance-covariance matrix.

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IMPRESSIONS OF THE CONFERENCE

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My impression of the conference is that there are three main areas in oceanography in which observations from satellites may be of considerable value:

1. Use of infrared, radar, and microwave for ice reconnaissance. (As used here, the term radar pertains to an active system and the term microwave to a passive system, i.e., microwave radiometry.)
2. Use of all methods for world-wide reconnaissance of beaches, their changes in size and shape, and possibly of spectrographic methods to determine mineral content.
3. Use of radar backscattering from the sea surface to determine a roughness parameter of the sea surface for wave research reconnaissance and prediction.

The outlook for using satellites to obtain data for sea surface temperature (SST) charts, which would be of great interest to our Laboratory, is less optimistic. Even in the so-called "atmospheric window" within the infrared band, the absorption of radiation by atmospheric water vapor produces an error of 10-20°C which may be corrected only to an accuracy of about ± 3.0°C. These techniques, which can scan a relatively narrow field and have a rapid response, could be used in the absence of clouds for delineation of sharp temperature gradients, such as along the boundary of the Gulf Stream, but do not seem suitable for studying year-to-year changes in temperature. The working group on sea surface temperature, chaired by J. P. Tully and one in which I participated, felt that for mapping of surface temperature an average temperature accurate to ± 0.5°C integrated over an area of no more than about 600 square nautical miles was necessary to give new useful information. Use of microwave radiometry, which will penetrate clouds, is hampered by changes in the emissivity of the sea surface with changes in surface roughness or waves, and little quantitative information is available as yet about this. Element response time is slow so that an integration time of 3 seconds (satellite movement: 15 miles) or more is necessary.

I made some brief comments on our Laboratory's interest in SST data. In these I noted that, although determination of SST is beset with certain problems, it is well to keep in mind the potential value that would arise should a method be developed for determination of water vapor and the correction to give SST accurate to 0.5°C. A satellite in a polar orbit would probably get 3 daytime and 3 night looks at a geographic location, which would be 180 per month. Thus, if a clear observation without clouds could be obtained only about 2% of the time, this would give a sampling of about 3-4 observations per month. There are now large areas of the tropical and south Pacific and the Indian Ocean in which we now get observations only a few times a year, so that this would be an increase in data essentially by an order of magnitude.

The purpose of the conference was to consider observations which could be made with the sensor in the satellite. However, the potential value of satellite communications from buoys, fixed stations, and ships was deemed so great that a working group was organized by Dr. James Bush, I.I.T. Research Institute, Chicago, on this subject. Its recommendations, which are to be included in the report, are general but serve to point out the importance of this aspect.

Another thought which arose throughout the conference was of the value of just placing a trained observer in a satellite in orbit around the earth. It was felt that such an observer might well discover sources of information which could be obtained from the satellite, but which would never occur to the persons sitting in the conference room. One scientist stated the problem in the following words, "We need the manned satellite to find out what to look for with the unmanned satellites." Dr. Badgely assured the conference that NASA is aware of this and is already thinking along these lines.

The report of the Panel on Marine Biology noted that visual observations of bioluminescence, discolored areas, animal life and convergences; selective spectrometry for chlorophyll concentration; and monitoring of commercial and sport fishing fleets; would be of great use to biologists, as would telemetered information on surface and subsurface sensors.

A difficulty relating to the orientation of the satellite is encountered when one wishes to determine the geographic location of something in a photograph in order to use stereo methods for measurement of height or speed of movement from two photographs separated in time, e.g., on consecutive orbits. The track of a satellite is quite stable and can be measured and predicted with great accuracy, so that this can be used by surface ships with electronic gear to determine their position accurately-the navigational satellite. However, if one has a satellite photograph (visual, infrared, or microwave) the vertical orientation of the satellite cannot at present be governed nor measured to give a location better than about ± 30 miles in the photograph when there are no fixed reference points in the photograph, i.e., physical features of known geographic location.

A number of participants were apprehensive that much of the proposed effort might become classified because of security regulations. NASA personnel indicated that they have attempted to get observational information released and have had fair success in this, even though the full capabilities of the sensor might be classified. The conference went on record to the effect that "present security restrictions are: (1) impeding the applications of many sensory techniques to important scientific problems and (2) preventing interpretation of existing data by scientists of recognized ability, which results in a loss to both military and non-military projects of scientific nature.

Reprinted from OCEANOGRAPHY FROM SPACE, Gifford C. Ewing, Ed.
Ref. No. 65-10, Woods Hole Oceano graphic Institution, April 1965.

OCEANOGRAPHIC OBSERVATIONS FROM MANNED SATELLITES FOR FISHERY RESEARCH AND COMMERCIAL FISHERY APPLICATIONS

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The broad mission of the Bureau of Commercial Fisheries (BCF) is to conserve the Nation's fishery resources and strengthen its fishing industry through research, development and services. At the Biological Laboratory, Stanford, California, our research in "fisheries oceanography" is directed toward establishing the effects of changes in the meteorological and oceanographic environments upon the changes in abundance and availability of commercial fishes. Although I have sought to determine general interests of BCF Laboratories in the Pacific area, the thoughts and emphasis which are placed on oceanographic observations from heavy payload or manned satellites will naturally be colored by my own interests in physical oceanography.

When we attempt to establish some history of events in the North Pacific Ocean, the glaring lack of time-space continuity in any form of oceanographic observations, with the possible exception of poor quality sea surface temperature data, becomes immediately apparent. The use of satellites as a communication link to shore from ships, buoys, and fixed stations as a method to extend and improve geographic coverage and to obtain data, particularly below the surface, on a real-time or synoptic basis stands out as an obvious, and perhaps the most promising, benefit to be derived from the use of satellites for oceanography. This subject has received much attention, e.g., by R. T. H. Collis and R. E. Nagle*, and it seems unnecessary to dwell further on it here. It is well to remind ourselves, however, that it is not necessary to await the perfection of complex oceanographic buoy systems, because there are many rocks, shoals, uninhabited islands, and inaccessible coastal regions on which a fixed automatic station could be constructed for making observations. It could even be advantageous to have sites offshore from present coastal stations which were tied into a single communication system.

This conference, however, is concerned primarily with observations which would be made with sensors located in the satellite. The development of methods for obtaining cloud cover, radiation balance, and sea surface temperature (SST) has already begun in the TIROS series of satellites. Here I might suggest that for synoptic charts of SST the instrumentation goal be a resolution of a 50-mile diameter circle and an accuracy of $\pm 0.5^{\circ}$ C. Greater resolution would be necessary for special studies, such as meanders in the Gulf Stream or oceanic fronts.

Turning now to other observations which might be made for oceanographic or fisheries research, it seems appropriate only to set forth a few thoughts or brief suggestions for conference discussion. The order of listing has no particular significance as to importance or priority.

Visual, photographic or televised observations of marine flora and fauna: seaweed fixed or drifting; plankton blooms, such as red tide; fish schools, eg., herring, sardine, tuna, anchovy, etc.; large sharks, e.g., the basking shark and great white shark, and whales. Not only is the identification, number and size of schools important, but also the movement or migration and the behavioral patterns. Such observations would require resolution at scales of one meter to one mile. Until such resolutions become available the satellite could be used to relay observations from surface ships on a real-time basis as noted in the next paragraph.

Locations of fishing boats and fishing fleets on a daily basis: This would help to increase efficiency of fishing operations. An associated problem is the failure to receive on a short-

*Survey of Requirements for a Geophysical Data Collection System. Stanford Research Institute, Final Report to NASA on Contract NASr-49(12), August 1963, pp. 66.

time basis many potentially valuable meteorological and oceanographic observations made by fishing boats because many are unwilling to use the marine radio and possibly reveal their locations to competitors. VHF communication to satellite might provide the "security" which would engender greater cooperation by the fishing boats in reporting these observations. It should also be noted that a continuous monitoring of the location of all ships at sea would be a great factor in improving marine safety.

Marker, transponding and command buoys: In addition to the normal tracking of drifting buoys and communication of observations from instrumented buoys, some buoys, when visible from the satellite, might be commanded to release smoke, fluorescent particles, or dye for assessing wind and current structure and for making diffusion observations in the atmosphere and ocean. Deep currents might also be measured over long periods of time by adapting Swallow floats with time-release pop-up markers to be detected by satellites.

Laser radar or LIDAR (light detecting and ranging): These devices have shown promise for detecting clear air turbulence and atmospheric pollutants below the level of detection of the human eye. Potential uses which might merit further investigation are (1) for the determination of corrections for atmospheric absorption to improve the accuracy of sea surface temperature charts and (2) for observations of turbulence near the surface to assist in the evaluation of evaporation and heat transfer, and thereby increase accuracy of heat budget computations.

Productivity of the ocean: The possibility of assessing and monitoring the productivity seems indeed remote, because there is difficulty even now in standardizing and interpreting observations which can be made from ships. Nevertheless, there are a few possibilities for making qualitative or semi-quantitative observations, such as color and changes in color. Perhaps it would be possible to use LIDAR instruments at several different frequencies to determine the back scattering in the surface layers and thus obtain a measure of particle size and concentration.

The above comments indicate that I have come to this conference as a user of data, seeking information on instrumentation and methods of obtaining data of interest to me. I can assure you there are other scientists of the Bureau of Commercial Fisheries Laboratories in the Pacific area who are also deeply interested in obtaining the types of data I have mentioned.

Reprinted from OCEANOGRAPHY FROM SPACE, Gifford C. Ewing, Ed.
Ref. No. 65-10, Woods Hole Oceanographic Institution, April 1965.

Made in United States of America
Reprinted from THE JOURNAL OF PARASITOLOGY
Vol. 51, No. 6, December 1965, p. 1016–1017

Molting and Exsheathment in vitro of Third-stage *Dirofilaria immitis*

The molt and exsheathment in vitro of infective third-stage *D. immitis* larvae from mosquitoes has been reported by Taylor (1960, Exp. Parasit. **9:** 113–120), Sawyer (1963, J. Parasit. **49:** Sect. 2, 59), and Yoeli et al. (1963, Exp. Parasit. **15:** 325–334). The present report describes some of the effects of mammalian serum, *p*H, and temperature of incubation on the survival, molting, and exsheathment of these larvae. Tissue culture medium NCTC 109 supplemented with serum and antibiotics was used throughout the experiments (Sawyer and Weinstein, 1963, J. Parasit. **49:** 218–224); cultures were gassed with a 5% CO_2–air mixture.

Serum. (1) Ten per cent human serum in NCTC 109: survival for 12 to 15 days; exsheathment of approximately 100% of the healthy larvae (Figs. 1, 2). (2) Ten per cent horse serum in NCTC 109: survival and exsheathment the same as with human serum. (3) Ten per cent normal dog serum in NCTC 109: survival for 6 to 9 days; exsheathment of approximately 25% of the healthy larvae. (4) Ten per cent serum from each of four *D. immitis* infected dogs in NCTC 109: survival for 3 to 5 days; exsheathment of 0 to 25% of the healthy larvae. Larvae in medium supplemented with such "infected" dog serum usually were inactive throughout the cultivation period and most of them did not exsheath. Precipitates which ranged from small anal or oral plugs (Fig. 3) to extensive cephalic masses (Fig. 4) were noted only in these cultures. The small plugs were seen in cultures containing serum from each of the four dogs, while massive precipitates occurred only in the presence of serum from one of them. Whether these precipitates were due to an antigen–antibody reaction remains to be determined. Larvae that were damaged during dissection from mosquitoes often developed cephalic masses of degenerating cytoplasm which were easily differentiated from the precipitates mentioned above.

pH. Exsheathment occurred routinely in medium NCTC 109 containing human or horse serum when cultures were maintained in an atmosphere of 5% CO_2 in air, *p*H 7.2 to 7.6. In serum-free medium studied under the same conditions fewer larvae exsheathed, vacuolization was extensive, and survival was shortened to 3 days or less. Above *p*H 7.6 (7.8 to 8.2) in cultures not gassed with 5% CO_2–air mixture, only small numbers of larvae exsheathed in medium containing serum, while none of them exsheathed in serum-free medium. Exsheathment was not studied below *p*H 7.2.

Temperature. The experimental results obtained at 37 C are presented above. At 21 to 25 C larvae maintained in medium NCTC 109 containing either human or horse serum survived for periods up to 22 days. After 7 to 10 days of cultivation a clear space formed between the body and the cuticle along the entire length of some of the larvae and was interpreted as an incomplete molt since it was not followed by exsheathment. However, at 37 C this "sheath space" was present after 48 hr of cultivation and was clearly visible just prior to exsheathment.

Maximum development of exsheathed larvae appeared identical to that obtained after 5 days growth in dogs (Orihel, 1961, J. Parasit. **47:** 251–262), in rats (Sawyer and Weinstein, 1965, J. Parasit. **51:** Sect. 2, p. 48), and in culture (Yoeli et al., 1964, Exp. Parasit. **15:** 325–334). Daily observations of the larvae showed that a protracted quiescent period occurred only during the time of molt. This corresponded very closely to the lethargus of larval *Haemonchus contortus* described by Veglia (1915, Rept. Vet. Res. S. Afr. **3** and **4**, p. 349). Inasmuch as exsheathment did occur, although at a low level in serum-free medium, it may be possible with improved methods to determine the presence of exsheathing fluids (Sommerville, 1957, Exp. Parasit. **6:** 18–30).

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FIGURES 1–4. Third-stage larvae of *Dirofilaria immitis*, development in vitro. **1**, **2**. Exsheathment after 72 hr in tissue culture medium NCTC 109 with 10% human serum. **3**. Oral plug of precipitate in NCTC 109 with 10% serum from dog with *D. immitis*. **4**. Massive cephalic precipitate occasionally observed in NCTC 109 with 10% serum from infected dog. All figures × 430.

The Cephalic Hook in Microfilariae of *Dipetalonema reconditum* in the Differentiation of Canine Microfilariae

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Reprinted from Proceedings of The Helminthological Society of Washington
Vol. 32, No. 1, January 1965, p. 15–20
Made in United States of America

The Cephalic Hook in Microfilariae of *Dipetalonema reconditum* in the Differentiation of Canine Microfilariae

THOMAS K. SAWYER,[1] ELLIS F. RUBIN,[2] AND RONALD F. JACKSON[3]

The specific identification of microfilariae from dogs in the United States usually is made on the shape of the tail, the superficial appearance of the head, and on motility. More critical examination may include the R-cell patterns[4] and measurements of the microfilariae (Newton and Wright, 1956; Wallenstein and Tibola, 1960; Lindsey, 1961; Sawyer *et al.*, 1963). The present report describes the rediscovery of the cephalic hook in the microfilariae of *Dipetalonema reconditum* and outlines a staining technique to reveal this hook and to more clearly distinguish the R-cells in the microfilariae of both *D. reconditum* and *Dirofilaria immitis*.

This study was initiated when a cephalic hook was observed on the microfilariae of *D. recon-*

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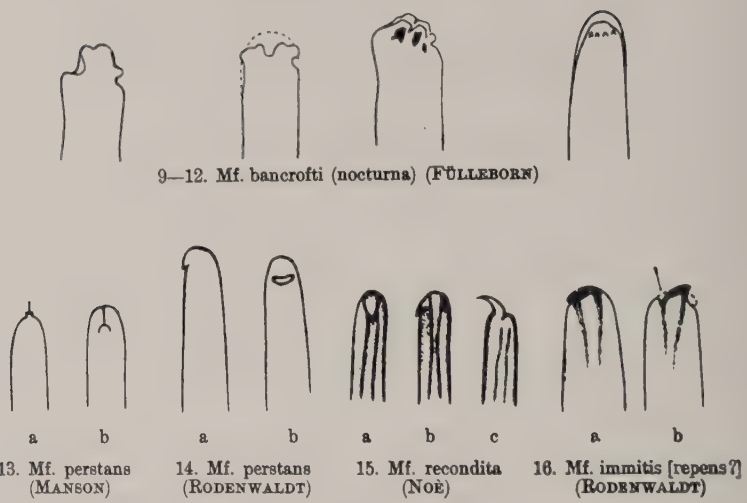
The authors gratefully acknowledge Mrs. Maybelle Chitwood, Beltsville Parasitology Laboratory, U. S. Department of Agriculture, for her cooperation in reviewing the older literature and for calling attention to the earlier descriptions of Fülleborn; Mrs. Margaret Johnson, Laboratory of Neuropathology, NINDB, NIH, for suggesting the use of brilliant cresyl blue during an earlier study of microfilariae from monkeys; and to Mr. Donald Tyson, Photographic Section DRS, NIH, for preparing Fig. 15 and suggesting the use of high-contrast film for the photographs of the cephalic structures.

[4] These four cells (R-cells) were reported by Taylor (1960c) to form the intestine and rectum in *D. immitis*, and are synonymous with the so-called G-cells incorrectly presumed by some earlier workers to form the genital primordium.



Text-Fig. 1. Cephalic structures of microfilariae (reproduced in part from Fülleborn, 1913). a, b, and c are different views of the same species.

ditum in unfixed blood films stained with brilliant cresyl blue, and the significance of the finding was determined when a search of the older literature led to an illustration of this structure by Fülleborn (1913). The commonly used methods of fixing and staining microfilariae for study usually do not reveal the cephalic hook, a fact which no doubt accounts for the lack of references to this structure in the more recent literature. Accordingly, it was thought worthwhile to bring this morphological characteristic to the attention of other workers and to present a method for demonstrating it. In addition to revealing this hook, the stain provided a method by which the R-cell pattern was easily distinguished.

Methods

Microfilariae of *D. reconditum* were studied from fresh blood samples of seven dogs at NIH, and from formalin-treated sediments from six dogs shipped from other locations (California, Florida, Kansas). The microfilariae from these 13 dogs were identified on the basis of measurements obtained with the modified Knott technique of Newton and Wright (1956) or the saponin–formalin technique described in an earlier study (Sawyer *et al.*, 1963). Microfilariae of *D. immitis* from four other dogs at NIH were identified using the same techniques. Microfilariae of both species were then studied on unfixed blood films stained with brilliant cresyl blue, as follows: (1) Thick blood films from blood taken from marginal ear vein were stored overnight at room temperature. (2) Dehemoglobinized in tap water or saline for 10 minutes or less (depending on thickness of individual films). (3) Films were transferred without drying, to 1 : 50 dilution of 1% brilliant cresyl blue (both stock and diluted stain are prepared in 0.8% NaCl). (4) Rinsed twice in saline and mounted in saline, cover slip sealed with melted vaseline–paraffin. (5) Films then examined with both high dry and oil immersion objectives.

If desired, such stained slides can be stored in petri dishes lined with moistened paper toweling for subsequent study.

The results obtained with the brilliant cresyl blue stain were compared to those obtained with several routine techniques.

Photomicrographs were prepared using both Versapan (Ansco) and high-contrast (Kodak) sheet film.

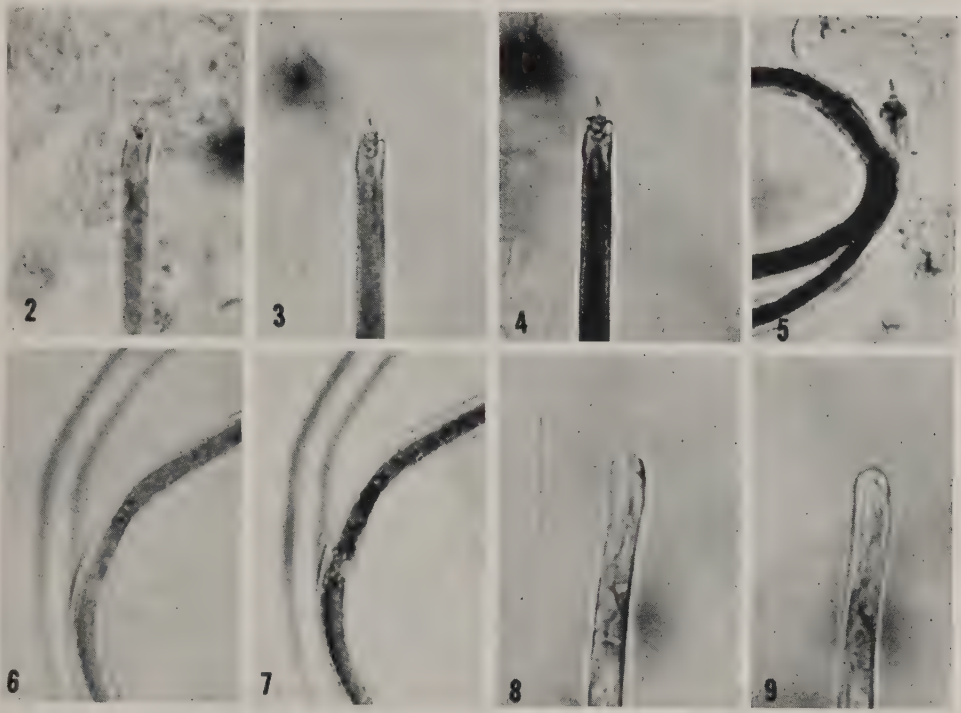


Fig. 2. Cephalic hook and "roten Mundegebilde" of *Dipetalonema reconditum*. Ansco film, × 700.
Fig. 3. Cephalic hook of *D. reconditum*. Ansco film, × 700.
Fig. 4. Same as Fig. 3. Kodak high-contrast film, × 700.
Fig. 5. Cephalic hook of *D. reconditum*. Kodak high-contrast film, × 700.
Fig. 6. Excretory pore and excretory cell of *D. reconditum* stained with brilliant cresyl blue. Ansco film, × 700.
Fig. 7. Same as Fig. 6. Kodak high-contrast film, × 700.
Fig. 8. Microfilaria of *D. reconditum* in formalin sediment. Note absence of hook with specimen in optical focus. Ansco film, × 700.
Fig. 9. Same specimen shown in Fig. 8. Note folded hook with specimen in upper plane of focus. Ansco film, × 700.

RESULTS

Unfixed microfilariae of *D. reconditum* on blood films stained with brilliant cresyl blue regularly showed the distinct cephalic hook illustrated by Fülleborn (Text-Fig. 1–15b, Figs. 2–5). When the modified Knott technique was employed, the only distinguishing features were the narrow blunt outline of the head, the distinct excretory pore and cell (Figs. 6–7), the "inner body," and usually the "button-hook" tail. With this technique the microfilariae were fixed simultaneously with the lysing of the blood and there was a pronounced contraction, or folding, of the cephalic hook. Only rarely could the folded hook be seen and then only with the most careful focusing on different levels of the organisms (Figs. 8–9); it certainly would not be readily seen in routine examination. When blood was lysed with saponin instead of formalin, the living unstained microfilariae could not be critically studied because they were too active and frequently were attached to clumps of leucocytes which masked the various structures.

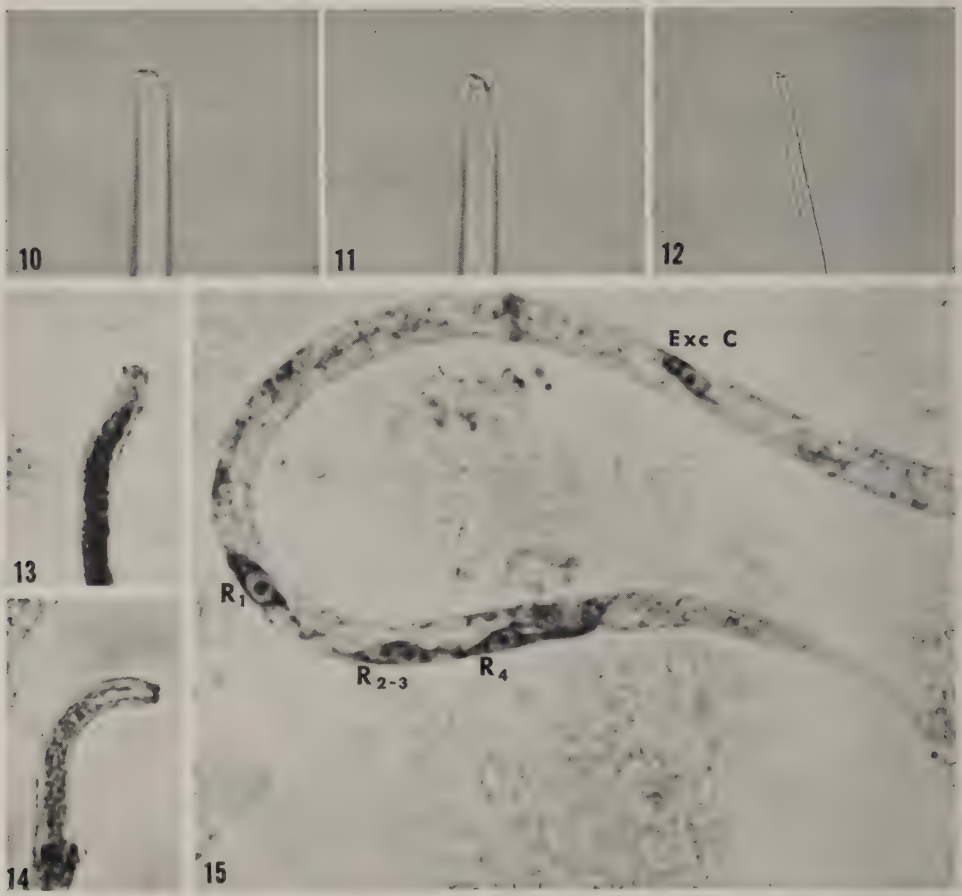


Fig. 10. Cephalic hook of *Dipetalonema reconditum* in saponin–formalin sediment, × 700.
Fig. 11. Cephalic hook and groove of *D. reconditum* in saponin–formalin sediment, × 700.
Fig. 12. Low magnification of cephalic hook of *D. reconditum* in saponin–formalin sediment, × 220.
Figs. 13 and 14. Cephalic structures of *Dirofilaria immitis* stained with brilliant cresyl blue. Kodak high-contrast film, × 700.
Fig. 15. Excretory cell and four R-cells of *D. immitis* on blood smear stained with brilliant cresyl blue. Kodak high-contrast film, approx. × 800.

However, as motility decreased with continued exposure to saponin or was arrested by slowly adding 2% formalin, the flexible hook was somewhat retracted but clearly visible in many of these specimens (Figs. 10–12).

As a result, freshly prepared Giemsa-stained thin films and such slides previously prepared from three dogs were carefully examined and reexamined for the presence of the hook, which might have been overlooked in previous studies. As with the formalin-lysed whole blood, the hook could be detected in about one specimen out of every five examined from all three dogs. The hook was poorly stained and difficult to distinguish; it could hardly have been recognized in routine examination.

Microfilariae of *D. immitis* similarly stained with brilliant cresyl blue did not show a cephalic hook. The cephalic structures of this species appeared as a cavity containing a cuticular disc surrounded by flexible lips (Figs. 13–14). A very fine barb appeared to be present on the disc of many but was not always clearly visible. When the Giemsa stain was employed for staining dried blood films, the cephalic features of *D. immitis* were unstained or lightly stained and only the clear cephalic space containing the "roten Mundegebilde" was discernible.

In sediments of *D. immitis* microfilariae from blood treated with the modified Knott technique the head was wide and tapered but details of the lips and cuticular disc were obscured; in these preparations the barb was never seen. In contrast to specimens of microfilariae of *D. reconditum* similarly treated, the excretory pore and cell were not distinct and the tail was wide for a greater portion of its length. Unlike the microfilariae of *D. reconditum*, the living unstained *D. immitis* microfilariae in saponin-treated blood were not usually attached to cell clumps or to the glass slide, and they rarely moved from the microscopic field.

Further examination of unfixed blood films stained with brilliant cresyl blue revealed that the R-cells of both *D. immitis* and *D. reconditum* were large and distinct in most of the specimens on any given slide. The complete group of four cells was detected in approximately 90% of the specimens of *D. immitis* (Fig. 15) but, due to the tendency of *D. reconditum* microfilariae to coil during drying, these cells could be readily distinguished in only about 50% of these microfilariae. Furthermore, the "clear cephalic space" described from routine films is not really clear. With the brilliant cresyl blue stain, distinct hook muscle cells which have been described by Taylor (1960b) can be readily seen in this area, particularly those of *D. reconditum* microfilariae.

DISCUSSION

The cephalic hook illustrated by Fülleborn (1913) and the hook muscle cells described by Taylor (1960b) are readily seen in almost every unfixed microfilaria of *D. reconditum* stained with brilliant cresyl blue. In methyl alcohol- or formalin-fixed preparations the cephalic structures are so shrunken that the presence of the hook can rarely be detected and the muscle cells are never seen. Since the microfilariae of *D. reconditum* are usually few in number and in the present series many slides were negative or with rarely more than two or three microfilariae per slide, a concentration technique is desirable. Fortunately, the hook may be readily seen in unstained microfilariae in saponin-lysed blood. Curiously enough, subsequent formalin fixation of microfilariae in saponin-treated blood does not appear to produce the same shrinkage of the cephalic hook which results when the modified Knott technique is employed.

No hook was seen in any of the *D. immitis* microfilariae, but a very fine barb was seen in the cephalic end of some of them. What relation, if any, this barb bears to the cephalic hook on *D. reconditum* microfilariae, or to the cephalic hook described in young embryos of both *D. immitis* and *Litomosoides carinii* developing *in utero* (Taylor, 1960a), is not evident at present.

The value of the cephalic structures in the identification of filarial parasites has received little attention apparently because routine fixing and staining methods may obscure these features. The illustrations by Fülleborn (1913) clearly indicate that microfilariae described in recent years should be reexamined employing unfixed specimens stained with vital dyes, or when possible by more specialized procedures as phase contrast microscopy (McFadzean and Smiles, 1956), ultraviolet microscopy (Taylor, 1960b, 1960c), and agar mounts (Taylor, 1960b; Esslinger, 1962). Recently, a large cephalic hook on microfilariae of *Brugia pahangi* was discovered by means of the agar pad (Esslinger, 1962) which was not included in earlier descriptions. Of seven species of *Brugia* (Ash and Little, 1964) the cephalic structures have been described only for *B. pahangi* (Esslinger, 1962) and *B. malayi* (Taylor, 1960b). Nelson described distinct hooks, or lancets, on the developing first-stage larvae (from insects) of *Dipetalonema manson-bahri* (1961) and *D. reconditum* (1962) which were detached with the first ecdysis. This structure on the developing larvae of *D. manson-bahri* described by Nelson (1961) appears

to be identical to the hook that we have seen on microfilariae of *D. reconditum* in fresh blood. This structure may be present but unrecognized in many species of microfilariae.

Because other unrecognized filarial infections may be present in dogs in the United States (Rothstein, 1961; Lindsey, 1961), it is important that microfilariae be examined carefully using various techniques. From the results obtained with both fixed and unfixed blood sediments and blood films, it is evident that morphological distinctions among microfilariae may be incomplete when only one method of examination is employed.

Summary

A staining technique for microfilariae using brilliant cresyl blue is presented which clearly demonstrates the cephalic hook of *Dipetalonema reconditum*, a morphological feature which is not readily discernible with the commonly used methods of fixing and staining. Microfilariae of *Dirofilaria immitis* stained by this method did not reveal a cephalic hook, but a fine barb was sometimes seen. The R-cells of both species were more distinct when stained with brilliant cresyl blue than when stained with the routine Giemsa stain. This staining technique offers a method for examining some of the morphological features of microfilariae that are often poorly stained and overlooked. The presence of the cephalic hook in microfilariae of *D. reconditum* and the absence of such a hook in those of *D. immitis* may offer yet another tool for the differential diagnosis of canine filariae.

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SOME ASPECTS OF BEHAVIOR IN CLUPEID LARVAE

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One of the most interesting phases of my project of rearing larvae of pelagic fishes has been the opportunity to investigate some aspects of theories proposed to explain peculiarities of feeding and high mortality among clupeid larvae. Owing to the marked decline of Pacific sardine (*Sardinops caerulea*) populations off the coast of California, particular emphasis has been placed on studying the larval history of this fish.

Sardine larvae can be placed into a natural assemblage of fish larvae possessing non-functional optic, oral, digestive and excretory systems at hatching. Food reserves in the form of egg-yolk are generally small in this group, and the larvae also seem to be exceedingly sensitive to largely undetermined environmental factors affecting survival during early larval life. In addition to pelagic larvae this group includes some larvae originating from demersal eggs of marine and freshwater species as well.

LARVAL MORTALITY

One of the primary considerations in studies of clupeoid fishes, and particularly in studies on the Pacific sardine has been the elucidation of factors responsible for mortality of larvae during a period up to and including metamorphosis of larvae to the adult body form. As in all fish spawning large numbers of eggs, an enormous reduction in numbers of individuals occurs between the egg and adult. Although it was known long ago that mortality must be highest in the earlier life stages, it is only recently that anyone has attempted to learn just when and where in time this took place.

Early attempts at rearing the pelagic young of some marine fishes were for the most part futile, even though a quite comprehensive hatchery technology had been developed for rearing many species of freshwater fishes. Two of the earliest investigators of pelagic marine fish larvae, Fabre-Domergue and Biétrix (1897), noted that small marine fish larvae being reared in aquaria died soon after the yolk-sac was absorbed and the tiny larvae became dependent upon the environment for nourishment. Because mortality was low or absent during embryonic, and the prolarval stages, and high when the yolk reserve was exhausted and the larva began to search for food, some significance was attached to rate of survival during the first days of active life. This time of apparent extreme sensitivity to the environment was termed a "critical period." Later Hjort (1914, 1926) discussed a critical period concept whereby in general fish larvae were thought to have sensitive periods particularly in relation to their food supply.

Specifically, a "critical period" is thought to be a time when larvae are prone to markedly increased mortality over a short time span. "Short time" in this context may be a matter of several days to several weeks depending upon the species of fish and period in the life history. For instance, a "critical period" for sardine larvae reared in aquaria (although not definitely established for larvae in nature) may occupy a time interval of between several hours to several days, may occur more than once during larval life.

Attempts to study the rate of survival of various species of fish larvae in nature have proven difficult. Although much of our still inadequate information concerning survival has been drawn from studies of economically important freshwater fish populations, our knowledge of the details affecting survival of fish from the time of hatching to some early juvenile stage is fragmentary even for the most intensely studied and easily accessible freshwater fish species. It is not surprising, therefore, that although special interest and studies concerning the fate of pelagic eggs and larvae of various marine fishes took shape some 60 years ago, very little factual information is at hand on details concerning survival of larvae in the open sea.

One of the most informative studies on the survival of sardine eggs and larvae over the major portion of the distributional range, has been that of Ahlstrom (1954), whose Figure 32 (p. 138) is reproduced here as Figure 1. It may be seen that losses seem to be quite high between the final egg stage (hatching) and larvae of 3.25 and even 5.75 mm is length.

It would be of considerable importance to know precisely when losses took place because if mortality were actually high during a limited period of time, a few days after the yolk was absorbed, for instance, then the term "critical period" might have special biological significance. The factors causing mortality might then be sought in the physiology and particular food relations of larvae during the short time when they become wholly dependent upon external sources of nutrition and first subject to the stresses of an active life.

On the other hand, if losses were of a high but decreasing intensity over the first weeks of life, no one period could logically be considered as potentially more hazardous for sardine larvae than any other period. Mortality would then be a form of continuous environmental attrition removing a percentage of the larval population. Factors causing mortality might then be expected to be any or all normal dangers of life such as disease, predation, food supply and the like.

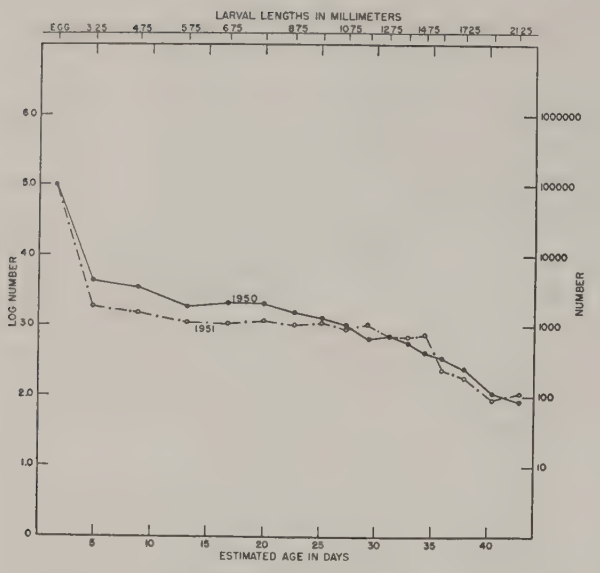

FIGURE 1. Survival of sardine larvae in the sea based on numbers of larvae in net samples (after Ahlstrom, 1954).

In discussing his Figure 32, Ahlstrom points out that although there seems to be an abrupt decline in numbers of larvae during the yolk-sac stages of development (when larvae are independent of external sources of nourishment), it is more likely the loss is an artifact resulting from the escape of very small larvae through the meshes of the net. Marr (1956), in discussing the significance of this loss (p. 167), mentions that evidence suggests only one-tenth of 3.25 mm sardine larvae encompassed by the net used by Ahlstrom were retained by the meshes. Figure 1 shows that rate of survival seems fairly constant from about the 5.75 mm stage of growth to at least 12.0 mm, therefore it may be assumed that the net had reasonably good retention of larvae from at least the end of the yolk stage, or by the onset of feeding (5.0—5.5 mm) in sardine larvae. If this assumption is reasonable then the numbers of larvae reported by Ahlstrom to be present at the 5.75 mm stage of growth may have represented the actual situation, while numbers reported present in the 3.25 to 4.75 (or 5.0) mm stage may in actuality have been far higher at one stage or another, meaning after Marr, that the magnitude of increase could be nine fold at any point. In other words, escapement may mask when any sudden reduction in numbers may occur and the severity of such reduction. In any event, there seems little reason to doubt that quite rapid decline in numbers does take place in sardine larval populations between two fairly reliable points of population estimation i.e., the egg and 5.75 mm stage. The recent paper by Isaacs (1964) and the discussion elesewhere in this symposium show that when all data are considered (70,000 sardine larvae from 10,000 plankton hauls over the years 1950 to 1957) there is a steep mortality curve for sardine larvae ending at approximately 5.75 mm—6.75 mm.

It is not the purpose of this paper to enter too deeply at this time into the specific question of whether or not "critical periods" do actually exist in nature during larval development, but rather to present some facets of larval behavior occurring during the first weeks of active life. On the other hand, some interesting though tentative observations on survival rate of "populations" of sardine larvae in large aquaria seem worth mentioning here, particularly in relation to Figure 1. A curve describing the mode of survival of 200 sardine eggs, pro-larvae and larvae up to 12 mm in length (Fig. 2) very closely approximates the curves in Figure 1.

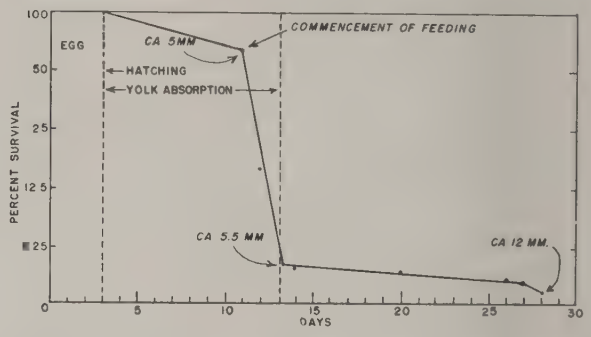

FIGURE 2. Aquarium experiment. Pattern of survival of 200 sardines at various stages of development.

In these aquarium experiments 200 sardine eggs of the same stage of development were allowed to hatch and a record maintained of daily losses in all stages of growth. Losses were very low or absent during the embryonic period; tests included a number of experiments with eggs collected at an early stage of development thus requiring about 2½ days to hatch (at 16°), and eggs held for longer periods at low temperatures. Losses were also low or absent during the pro-larval stage (7 days), while nutrition was obtained from the yolk supply. Approximately at the point, however, when larvae began actively searching for food (5.0–5.5 mm) while existing on stored energy and body tissue, losses began to mount rapidly. Only in exceptional cases was survival during the next three days better than 10 out of about 200 pro-larvae. In several separate instances, after 5 or 10 larvae had survived to a size of approximately 5.5 to 6.0 mm in length, no further losses were experienced until about the 11–12.0 mm stage of growth (about 30 days after hatching), and a time when larvae seemed to be changing their feeding habits, when losses again were high.

Rearing experiments by Blaxter (1962) with herring larvae seem to indicate a pattern of survival comparable to that found for the Pacific sardine. After an initially high mortality upon complete yolk absorption, surviving herring larvae had a low mortality until a later period in development when mortality was again high. Blaxter's Figure 5, reproduced here as Figure 3, is particularly interesting in that the overall pattern of survival in each experiment changed little although the actual number of larvae surviving subsequent to hatching varied from 10 to 50 percent.

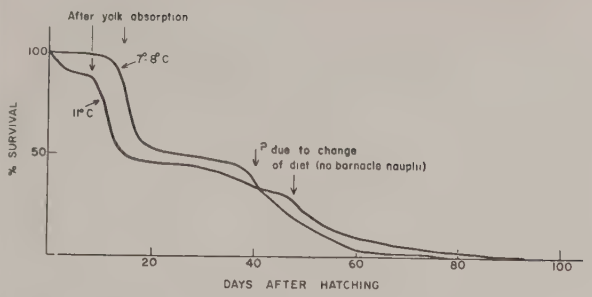

FIGURE 3. Aquarium experiments on survival of herring larvae at different temperatures (after Blaxter, 1962).

Ahlstrom's interpretation (p. 136–137) of his Figure 32 chooses between the seeming alternatives of a "critical period," or an artifact of net selectivity, to explain the abrupt decline between terminal egg and yolk-sac stages. Ahlstrom favored the latter explanation, but it seems at least possible,in light of the experimental results outline above, that both conditions might apply. In other words, nets are not sampling the earliest larval stages accurately enough to detect a period of increased larval mortality just prior to the 5.75 mm stage of development, if, following Marr's (1961) conclusion that nine-tenths of the very earliest larval sardine stages escape through the meshes.

The curves showing survival in Figure 1, level off somewhat in the section reporting abundance of larvae between 5.75 and 11.75 mm in length, the 1950 curve not showing quite as pronounced a flat section. In commenting upon the more or less level sections in the curves, Ahlstrom noted that "this means, interpreted literally, that mortality during this period of life was negligible, after having been precipitous immediately following hatching. This does not seem resonable. Net selectivity severest on newly hatched larvae [i.e., 5–5.75 mm larvae] and becoming progressively less severe with increase in larvae size, could produce a flat section of the curve." One might well ask why this type of survival is unreasonable, particulary in light of a similar "flat section" occurring in the rate of survival of clupeid larvae being reared under experimental conditions where predation of larvae was absent and the presumed main condition for larval survival was adequate quantities of food of the correct size and type.

Survival curves drawn from sampling at sea, and efforts at rearing sardine larvae are at present too incomplete to offer more than interesting parallels. However, it is in the small details of larval ecology and behavior—particularly the relation between the larva and its food organisms—that experimental rearing of pelagic fish larvae can aid studies on the same species of larvae in nature. For the period when feeding of larvae is governed by innate behavior, at least, it seems likely that normal behavior will be expressed whether the microcosm occupied by the larva be in the sea, or in an aquarium where it can be observed.

INCIDENCE OF FEEDING

Examination of various species of clupeoid larvae seems to indicate that incidence of feeding is very low (Lebour, 1921; Soleim, 1942; Arthur, 1956), in contrast to that of some flatfish (Scott, 1922), Cod, (Wiborg, 1948), and mackerel, (Lebour, 1920; Arthur, 1956). Theories on low incidence of feeding presume a number of factors being responsible for few clupeid larvae containing food in samples containing hundreds or thousands of specimens. The magnitude of the proportions—i.e. larvae containing food to those not containing food—as judged from tow net samples, is enormous in some species. For example, Berner (1959) found that in a sample of 13,620 anchovy larvae (*Engraulis mordax*) captured in the year 1954, only 211 contained food.

The chief artificial factor proposed to explain the low food content of captured larvae is that nets tend to selectively capture dead or dying larvae in disproportionate numbers, therefore low incidence of feeding may be an artifact of sampling (Arthur, 1956; Berner, 1959; Soleim, 1942). On the other hand, no one seems to have proposed an explanation of the cause underlying the natural occurrence of such quantities of dead or dying larvae in the plankton; Marr (1956) noted that poorly washed nets may have been contributory to such (artificial) occurrences in some cases.

Another possibility to which apparent low incidence of feeding could be ascribed, is that the majority of clupeoid larvae investigated come from samples taken at night when larvae are thought not to feed. It is possible that this objection is valid. However, Arthur (1956) noted that young sardine larvae of 5 to 6 mm in length contained about as much food at night as they did during the day, whereas older larvae containing food occurred only in samples collected during the day. This note is all the more interesting in light of observations of my own which suggest anchovy larvae of about 4 to 5 mm in length, hatched and reared out of doors in a 50 gallon aquarium, feed during the night or at least under very low light intensities. The larval hind-gut and frequently the mid-gut of the fish was filled with food organisms by 5:30 in the morning. The observed feeding frequency (the act of striking at food) indicated that the gut could not have been filled to the observed extent in the short period between dawn and time of observation.

As a general rule, however, we may assume that the majority of particulate feeding fish larvae will exhibit diurnal feeding habits, or at least have a higher food intake during the day than at night, and we may further assume that regardless of species more clupeid larvae will be collected at night than during the day. This also would hold true for most pelagic species, but even so, clupeid larvae seem to be noteworthy for the low number of individuals captured containing food.

Other theories accept low incidence of feeding among clupeoid larvae as a natural occurrence. Factors affecting low incidence of feeding include the possibility that food must be quickly digested and excreted because its presence in the gut would tend to make a transparent larva conspicuous and thus more subject to predation (Lebour, 1921). It is pre-

sumed that food is taken at long intervals and rapidly passed through the gut. Since the rate of digestion and gut clearance of sardine larvae has been established by Arthur (1956) at approximately 11 hours for 5.5 mm larvae and 3 hours for 10 to 25 mm larvae, the survival value theses of rapid digestion seems questionable, at least for sardine larvae. My experiments tend to confirm Arthur's data on the rate of gut clearance, although the rate of digestion of *Artemia* by sardine and anchovy (*Engraulis mordax*) larvae may vary from that for natural marine plankters. I have observed that an average of only 25 seconds is required by larvae of 15 mm in length or larger to pass an *Artemia* nauplius from the mouth to approximately one-half the length of the digestive tract (to a point just under the air bladder). Progress of a food particle (*Artemia*) through the remainder of the gut is much slower, with an average of two minutes required for food to reach the end of the gut and form a food plug.

The food of the jack mackerel (*Trachurus symmetricus*) has been found by Arthur (1956) to be substantially the same as that of sardine and anchovy larvae, but the ontogeny of the two body types and food capacities are very dissimilar. When they emerge from the egg, the jack mackerel is about 2 mm long and the sardine about 3 mm. Neither fish has functional eyes, mouth, or digestive system. Soon after the onset of feeding, (about 3.5 mm) the jack mackerel has developed a large head and capacious mouth. The sardine larva at this time is about 5.0-5.5 mm long and has a small head and mouth. The relative capabilities of the two types of oral apparatus may be seen in the progressive increase in food consumed by the jack mackerel larvae as compared to the anchovy, the latter being morphologically very similar to sardine larvae. Arthur notes (p. 95) that "at a length of 4.5 mm, the jack mackerel might contain about .004 cc of food. Assuming that the volume of the jack mackerel increases roughly by the cube of its length, then doubling its length would result in a body-volume increase of eight times; the volume of food, however, has increased about 200 times. The anchovy, while increasing in length from 4.0 to 7.0 mm theoretically increases in bulk by a factor of about 5.4 times. Its average food volume increases during this growth only by a factor of 1.25 times." It would seem, on the basis of these calculations, that low food intake may be a normal occurrence among clupeoid larvae, although low consumption does not rule out the possibility that the conversion of food to energy may be very high. Presumably the energy expended in hunting food is roughly similar in the two types, at least during early larval stages.

At onset of feeding, sardine larvae have been observed to spend only an average of 25 minutes per hour in motion, when food is captured, and an average of 35 minutes resting motionless in the water. The duration of each individual active or quiescent period lasted from roughly 30 seconds to 10 minutes, with a number of alternating active and quiescent periods occurring in one hour. It appears that there is a correlation between the length of time a larva had been active and length of the succeeding quiescent period, i.e. the longer (or more energetic) the active period was, the longer the duration of the following quiescent period. Several explanations for this behavior seem feasible. The most intriguing conjecture concerns the effect of the metabolite level which presumably increases during activity and which must be reduced—possibly by diffusion—as the larva rests motionless in the water. Small (5–7 mm) larvae do not show evidence of a well developed vascular system. Thus it may be assumed that waste products of metabolism, along with oxygen, pass through the skin by simple diffusion. It is interesting to note, in this context, that erythrocytes or at least hemoglobin, indicating an increased role of the blood in oxygen transport develop first in the larva at metamorphosis when the skin becomes covered by scales and thus presumably impermeable to diffusion. The motionless-drift period may also be a time when food is digested and absorbed and energy is conserved.

The yolk is exhausted at the 4.5–5.0 mm stage of development and larvae exist on their own tissue and whatever food they capture. An average of two units of effort (a striking motion) per 25 minute active period, to capture food is the observed situation at onset of feeding for sardine larvae held in aquaria. It is not known, in every instance, whether or not larvae are successful at every attempt at feeding. A deficit may be acquired during the 25 minute average active period of one hour, which may be rectified by a double success in a succeeding active period. It should be pointed out, in any case, that the margin between life and death in sardine larvae at onset of feeding seems exceedingly narrow (Lasker, 1962).

This type of alternating active and resting behavior, which limits food intake of sardine larvae, but conserves energy, contrasts with feeding behavior of some other pelagic fish larvae equal or smaller in size to the sardine larva at onset of feeding. Various species of 2-3 mm flatfish larvae, for instance have been observed to move slowly but constantly through the water feeding at short intervals on organisms in their path. Presumably flatfish larvae acquire more food when rich aggregations are encountered, but expend more energy than do sardine larvae when food is widely dispersed. The young of the California flying fish *(Cypselurus californicus)*, which hatch with an abundant food reserve, have been observed to swim continuously from the moment of hatching and to capture food *(Artemia)* while some yolk remained unabsorbed. Food is located by this fish, as in the large group of larvae from demersally spawned eggs, by traveling long distances in proportion to the body length. Most of the larvae in this group are physically, and probably physiologically, well developed at birth and rely less on chance—as does the sardine larvae at onset of feeding—to bring them into contact with food, than on their own swimming abilities.

One very interesting report concerning incidence of feeding raises some questions which observation on living material has been able to at least partially answer. Arthur (1956) states "Feeding incidence, when high, obviously implies . . . that a large percentage of

the fish larvae [in a net-tow sample] have been able to secure food. In other words, there is a relation between feeding incidence and the number of food particles per feeding fish, and the number of particles found in a larva should be related to its probability of securing a food particle during the digestive period. In one sample, 279 sardine larvae were captured, of which 200 had completed yolk absorption. Of these 200 potentially feeding larvae, 14 contained food and a total of 30 food particles were found in these 14 larvae. Using a Poisson type distribution for 30 particles scattered among 300 individuals, the expected number of larvae containing 0, 1, 2, and 3 particles was calculated. The expected number of particles becomes insignificantly low for 4 or more particles. The difference between the observed and the expected frequency distributions is that the actual larvae with food were fewer than the number calculated on the basis of chance, whereas the larvae with three or more particles were more numerous than calculated." Arthur goes on to say that "this may be explained by assuming that a larva that has captured one food particle has an increased probability of catching another within a unit length of time. Such a situation would follow if the larva is somehow conditioned by the first particle thereby increasing its efforts or ability to obtain a second or third particle." A second explanation of the disparity between the observed and the expected values within a sample was also discussed. The gist of Arthur's explanation is that it would be possible to capture with the same net, portions of two or more larval concentrations which had been living with dissimilar local plankton aggregations. This situation obviously implies a marked heterogeneity of plankton distribution within a small area.

Among the items of interest brought out by the above are 1) conditioning of feeding behavior, and 2) the problem of plankton dispersal, more specifically, the availability of food for sardine larvae.

CONDITIONING OF FEEDING BEHAVIOR

In the first instance, if sardine larvae can be conditioned to further efforts by the capture of food, presumably they would also be liable to frustration upon repeated failure. Both premises are valid for some species of adult fish at least. Soleim (1942) described a conditioning of non-feeding behavior in herring *(Clupea harengus)*, whereby the larva having failed to capture food after several attempts, gives up and ultimately dies. I have observed this behavior to occur at onset of feeding in sardine larvae, however, it is not entirely clear whether the fish experiences a loss of motivation, or simply exhausts its limited energy reserve, and in either case starves. Perhaps the stimulus provided by the act of capturing prey, or by food in the gut, engenders—or permits—further food getting activity.

A second assumption is that the larva increases its ability to obtain a second or third food particle; in other words, the larva learns to feed, becoming more proficient at recognizing, stalking and striking food organisms. Although learning undoubtedly occurs in later larval stages it seems probable that for the earliest larval stages feeding behavior is a reflection of ontogenetic development of inherited instinctive behavior patterns.

Limited observations of sardine and anchovy larvae indicate the presence of behavior patterns which probably have some influence on larvae finding food. One such pattern was observed most often after a sardine larva (6-7 mm) had captured food, or had attempted to capture food. The larva seemed to engage in a pattern of "search" in which after moving a distance in one direction, a 90° turn to the right or left was made and an equal distance covered before turning 90° again in the same direction. Some larvae were observed to turn six times, though the usual number of turns seemed to be three or four. Anchovy larvae also appear to stay within an area where they have been successful in obtaining food, but a distinct "search" pattern has not been observed in larvae of 4–5 mm in length which had been reared in aquaria.

It seems possible that the presence of a "search" behavior in sardine larvae may account for Arthur's (1956) observation that among larvae containing food, each individual contained more food organisms than could be accounted for by chance. In other words, a larva that has captured one food particle would stand an increased probability of catching another if instinct caused it to hunt in the same area where food organisms were aggregated. This seems to be the case rather than the sardine larva being a randomly oriented predator operating on a randomly dispersed food supply.

The feeding reflex of sardine larvae, conditionable or not, does not begin immediately after the yolk sac is absorbed. The transition from yolk nutrition to feeding upon other organisms seems to be interspersed with a short period in which larvae subsist on the energy derived from body tissue. This is indicated by slight shrinkage in the length of the body. Presumably an adjustment is necessary in the visual, or some other organ system, because during this period a larva will move about periodically with slow undulations of the body, pausing now and then when it perceives small organisms nearby. Visual perception is assumed because a larva would occassionally recoil slightly and the head and eyes would move although no attempt would be made to feed. Usually the larva drifted motionless in the water for several minutes before becoming active again. The first active interest in food is seen when a larva apparently tries to focus on a particle in the water. The body is slightly drawn into an S-shaped position and the head is jockeyed back and forth in what seems to be an attempt to keep a moving particle within a very critical point of focus. Apparently the stimulus to feed is not always high enough at this period to cause the larva to strike at whatever it is that it perceives. Presumably the larva and the particle drift apart and visual contact is lost, or the feeding instinct is latent and there is a loss of interest in the particle. The larva may abruptly break off its inspection and lapse into motionless drifting, or move away. In following periods the sinuous position of the body becomes more pronounced, the head moves rap-

idly back and forth, and the first attempt to capture a particle is made. Only one lunge is made at a particle at onset of feeding.

Sardine larvae which are successful in their first attempts at feeding develop in later stages an obvious proficiency at capturing food. A food particle is sighted and struck in rapid succession. After the larva has reached 7 mm in length the broad swimming undulations are followed by short, rapid undulations as food is sighted. The head of the larva moves from side to side and the eyes are in constant motion as the body is drawn into a pronounced S-shape and a rapid strike is made. Each of these acts progress smoothly and the hesitancy seen during the first attempts at capturing food is no longer observed. One has the distinct impression that visual acuity is improving and that the larva can perceive movement of food organisms at a greater distance—presumably the head must still be brought very close to an organism, however, before it can be recognized as "edible". As the larva grows in length, the rest periods become shorter and at about 9 mm the larva is in almost constant motion.

When *Artemia* ranging in size from newly hatched nauplii to several mm in length are introduced into a tank containing advanced sardine or anchovy larvae, it is at once apparent that larvae of about 15 mm in length obtain proportionally less food than larvae of 30 mm in length during the first few minutes of feeding. It is not primarily a question of fewer optimum sized *Artemia* being present that limits the food intake of the smaller fish, but it seems that smaller larvae still retain the early larval behavior of inspecting each food particle before eating or rejecting it. The larger larvae are at the point of metamorphosing to the adult body form and are possibly at the threshold of true filter feeding.

HOMOGENEITY OF PLANKTON DISPERSAL

The second item of interest noted under "incidence of feeding" concerned the relation between the sardine larva and the distribution of plankton in the larva's environment, and whether the potential food is uniformly dispersed or occurs in patches. This question is directly related to the availability of food, as opposed to the physical quantity present in a given volume of sea water. Present sampling methods tend to indicate the volume or mass of plankton present in a volume of water, but provide little information on micro-aggregations of organisms. In general, papers speculating on dynamics of larval marine fish populations equate numbers of invertebrate plankters with their availability as food, or, to put it another way, show that the ratio of larvae to food-mass is low, and therefore food is not of major significance to survival of larvae.

It seems evident from a perusal of the literature that the large volume of food organisms frequently associated with larvae in the contents of tow-net samples seems irreconcilable to the thesis that sardine, or other fish larvae may starve in the sea. The ratio of sardine larvae to potential food organisms has been calculated by Arthur (1956) who found a distinct "surplus" of food organisms. Arthur calculated the distance between food organisms on the basis of numbers caught per volume of water sieved by the tow-net, and gave a mean distance between food organisms as 10 cm or less at 70 percent of his stations, and 7 cm or less at 50 percent of his stations. This would seem to lend credibility to the notion that food for larvae is abundant in the sea, or that, as observed by Murphy (1961) "because of motion of food and larvae, only a short time need pass before a [sardine] larva has a food organism within easy reach." Random distribution of food is obviously assumed in this statement, because if an aggregation of food organisms were separated from a larva by only 20 cm, a great deal of time might pass before a 5 mm larva would find food within easy reach. The relative rates of drift for plankton aggregation and larva, in this circumstance, would be the same and even if the larva was disposed to swim four times its body length in one direction, there probably would be no clue as to the direction it must take to reach food. There is reason to believe, in fact, that 5 to 7 mm larvae are not capable of perceiving, or at least recognizing food organisms if they are more than a fraction of a millimeter distant. This statement is based upon many hours of observing larvae when they first attempt to feed.

During early stages of growth the larval sardine is incapable of much directed movement, thus if "chance of random encounter", produced by macro- or microcurrents in the sea, was the sole, or major means of sardine larvae obtaining food, any biological or physical phenomena which hindered random distribution presumably would in like degree hinder or prevent larval fish from feeding. The real problem then, is to establish what the true conditions are in the sea; i.e. not whether mixing of sea water takes place but whether such mixing has any effect on the spatial distribution of organisms. We are again subject to the limitation of not having very much information on just how small crustacea and other potential food organisms react to various physical influences which would tend to disperse them. Numerous studies of predator-prey relationships, among other pertinent studies have pointed up the fact that randomness of distribution of either predator or prey is exceedingly rare in nature and regardless of the physical conditions imposed upon a population of organisms—whether bacteria or crustacea nauplii—aggregation rather than dispersal is the general rule. Although the sea may present a somewhat more uniform aspect than land, distribution of pelagic organisms is known not to be uniform with depth and, after a number of investigators, has also been found not to be uniform in a horizontal plane. Barnes and Marshall (1951) for instance, concluded that various copepod nauplii, lamellibranch larvae, and unidentified eggs were not distributed at random, except at low population densities, but had a contagious distribution. It is interesting to note that although copepod nauplii and lamellibranch larvae would be able to resist dispersal by

micro-currents, the unidentified eggs being non-motile, would not. Conceivably micro-currents, or convergences in the sea may be more liable to concentrate organisms or particles than they would be to disperse such material. Phenomena such as foam-lines and slicks, denoting concentrating rather than dispersing action, are frequent at sea.

At this point we are confronted by a very incongruous set of data. On the one hand a low incidence of feeding among clupeoid larvae seems to be well documented from many parts of the world. On the other hand, calculations of the ratio of plankters to larvae—indicate an abundance of food in the sea. In both cases, however, the contents of tow-nets were assessed to obtain the data.

A third incongruity is provided by observation of larvae held in aquaria under experimental conditions. Sardine and anchovy larvae ranging in size from 15 to 17 mm in length have been found to feed continuously on *Artemia* when these organisms are offered as food. Both species have been observed to completely fill the gut in about ten minutes and to have an initial mean feeding interval of 17 seconds, i.e. a strike by a larva at an *Artemia* nauplius was observed to result in its capture. When the gut is filled and some digestion has taken place, after about 30 minutes, feeding slows down to approximately one *Artemia* per minute as long as food is present. Larvae larger than 17 mm fill the gut in less time and capture food much more rapidly by gulping one or more *Artemia* in continuous feeding.

One may well wonder, however, if this is "normal" behavior, and whether it is representative of feeding behavior of larvae in the sea under comparable conditions of high food concentration. If it is natural for clupeoid, or at least sardine and anchovy larvae to eat as much as they can hold when food is readily available, then a re-evaluation of our methods of estimating the abundance of the available larval fish food biomass is in order.

Very little information is on hand to judge the actual availability of food organisms to larvae under natural conditions, but one important study points up the necessity of further investigation on this question. In his study of the relation between larval fish and food organisms, Arthur (1956) observed an unusual natural occurrence of sardine and anchovy larvae behaving like the larvae held under the experimental conditions noted above. In this instance Arthur reported (p. 96) that "approximately 36 sardine and 264 anchovy larvae were in this haul. Twenty-seven of the sardine and 41 of the anchovy larvae were 10.0 mm or longer. The *unusual* (italics mine) aspect of the sample is that most of the larger larvae of each species were literally crammed with pteropods." This sample was omitted from the list of food eaten, as Arthur reported "because the number of pteropods found in this one sample is larger than the total number of food particles found in the larger sardine and anchovy larvae of all other samples examined. . ." In my opinion, the sample should have been retained as a rare natural example of food aggregation and larval feeding behavior. The natural biomass (pteropods) had, in this instance, very likely the same relative availability as the *Artemia* in the feeding experiments previously described, and the larvae which found themselves in this aggregation of pteropods ate to capacity.

The behavior of sardine and anchovy larvae, when one considers all aspects, seems intimately correlated to the behavior of the food organisms, indicating copepod behavior studies must be considered in conjunction with studies of larval fish ecology. Calculations of mean distances between food organisms may well represent only mathematical probabilities rather than biological actualities. The factors which influence fish populations cannot be viewed from the standpoint of all-encompassing equations, but rather must be studied as a series of minutiae which affect each individual step in the life history of fish from the egg to spawning adult. Each growth period or phase in the larval stage alone presents to the individual larva a new range of potentialities for success or disaster. My observations, limited as they are, indicate changes of survival tend to increase after the individual sardine has passed through one critical period at onset of feeding and very likely another period at about 11 to 12 mm in length. Thus agreeing in general with Marr's (1956) hypothesis that survival rate of sardine larvae increases at a nearly constant rate. Concomitant improvement in vision, the ability to range further in search of food, increased experience in capturing food, and the phasing in and out of certain behavior patterns throughout larval life all serve, to point up the large element of chance that determines life or death for sardine larvae at the critical onset of feeding. Probably at no other time in its life is the sardine so dependent upon the capture of food and so inadequately equipped to obtain it.

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54803—250 9-65 300

printed in CALIFORNIA OFFICE OF STATE PRINTING

COMPUTER PREPARATION OF SURFACE SEA TEMPERATURE OBSERVATIONS FOR ANALYSIS AND CHARTING*

by Dr. Oscar E. Sette[1]

SYNOPSIS

Surface sea temperature, as reported by the merchant marine and other ships, is now and will, for a number of years into the future, be the oceanographic property observed with best time and space continuity. This makes it a centrally dominant parameter for study of past broad-scale events in the ocean and their prediction in the future.

It is widely recognized that the surface sea temperatures as currently reported are of poor quality. The obvious direct remedial action is to provide proper instrumentation to cooperating ships as is done for certain meteorological instruments, such as barometers. A sea temperature instrument system is being developed and tested but it will be some years before cooperating ships can all be instrumented properly. As of 1964 there are about 3300 cooperating ships about half of which are U.S. flag vessels. To instrument these alone presents a funding problem of some magnitude which will require some years to solve. With the foreign flag ships it will probably take even longer.

In the meantime the currently reported sea temperatures, even though untrustworthy, are being widely used in military and fishery research and operations. It is highly desirable to improve the quality of the past and current data. It is possible to do so by computer analysis.

Error in the present reporting system stems from two sources: (1) personal factors and (2) poor instruments poorly located. The effects of the former are irregular but can be reduced substantially by computerized editing procedures such as have been highly developed in the Fleet Numerical Weather Facility at Monterey. The effects of the latter are systematic and, through studies made at the Bureau of Commercial Fisheries Biological Laboratory at Stanford by J. F. T. Saur, L. E. Eber and myself, have been found amenable to computer assessment. It is this aspect I wish to put before you.

In current practice the sea temperatures reported on ship's weather logs are a by-product of engine room operations which have far lower demands on temperature accuracy.

1. The instrument is a mercury-in-glass thermometer of uncertain calibration and coarse graduation.

2. It is mounted in the intake line where engine room ambient temperatures may exceed 100° F. This heat may be conducted through the metallic fittings or even along the stem of the thermometer.

3. It is often located so that parallax in reading is common.

These influences are relatively constant on a given ship, but differ between ships.

Assessment of these between-ship differences gives the mean "bias" of each ship relative to the sea temperatures reported by other ships. Such as assessment for the

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*Reprinted from "Proceedings of the ONR-NSIA Symposium on Automatic Collection, Processing and Analysis of Oceanographic Data", University of California, San Diego, 11-12 December 1964. Published for ONR and NSIA by Lockheed-California Company, 10-12-65.

last four months of 1962 showed that of 51,000 temperature observations nearly 4,000 (7.9%) were reported by ships having a bias of more than ±2.5°F and nearly 700 (1.3%) by ships having a bias of more than 4.5°F. Obviously such reports interject a substantial amount of "noise" into the sea temperature record, especially where observations are sparse. If one or two strongly biased ships are traversing such an area, their temperature can easily introduce spurious anomalies into the sea temperature field.

We are using the ship-bias values to "correct" the sea temperatures reported from the Pacific Ocean. This procedure renders the surface sea temperature data internally homogeneous by eliminating the bias of each ship relative to the other ships in the reporting fleet. It does not give the "fleet" bias relative to the true temperature. J. F. T. Saur (Journ. Applied Meteorology, Vol. 2, No. 3, June 1963, pp. 417-425) has determined that a group of 12 ships, none of them in the merchant marine, had a mean bias of +1.2°F relative to the true temperature. This is a small sample and not necessarily typical of the reporting fleet which is composed mostly of merchant ships. A further preliminary analysis involving merchant ships suggests that in the subtropical and tropical areas the fleet bias is about 1°F, both in winter and in summer; but in temperate latitudes in summertime the fleet bias si practically zero. The data were insufficient for a determination for the temperate zone winter. Until a more confident value, or set of values, is determined we are not including a correction for fleet bias.

Our computer program for determining ship bias and correcting reported temperatures is being applied to the temperature reported during the 14-year period 1949 to 1962. With the cooperation of the Fleet Numerical Weather Facility in further computer analysis and charting, we plan to produce an Atlas of Surface Sea Temperature of the Pacific Ocean (north of 20°S latitude) containing the 168 charts of the monthly mean fields for the 14-year period. This historical series is intended primarily for research on the responses of fish populations to large-scale changes in sea temperatures. Doubtless it will afford source material for many facets of research in physical oceanography and on air-sea interaction.

We hope that the series will be continued on a current basis through future years. Our experience suggests it is feasible to maintain an up-to-date calibration table for correcting temperatures reported currently and issued periodically. This is feasible because one month's run of data allows enough intercomparisons to provide calibration factors having an accuracy of ±1.0°F at the 95% confidence level for the ships which report 94% of sea temperatures. Because the calibration factors remain nearly constant from month to month, values in the past month's calibration table can be applied to the current month's data with little error except in the few instances where a ship's intake thermometer has been replaced or relocated. Up-dating the table at monthly intervals should keep these instances to an acceptably low number. With incoming data recorded on magnetic tape, 15 minutes of high-speed computer time is sufficient for producing the one-month calibration table for the Pacific Ocean.

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POND CULTURE OF OYSTERS—PAST, PRESENT, AND FUTURE

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Reprinted from Transactions of the Thirtieth North American Wildlife and Natural Resources Conference, March 8, 9 and 10, 1965. Published by the Wildlife Management Institute, Wire Building, Washington 5, D. C.

POND CULTURE OF OYSTERS—PAST, PRESENT, AND FUTURE

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The history of oyster culture in ponds dates back at least to the first century B. C. (Yonge, 1960). Designs on Roman vases reveal that oysters were cultivated in Lucrene Lake, Italy, by hanging them from horizontal stakes. Dean (1893) reported that the Roman methods of oyster culture were still in use in Italy. He stated that seed oysters were collected in Lake Fusaro on bundles of branches known as fascines, grown to market size, and then placed in baskets for final conditioning or fattening. He also described the method of oyster culture at Lucrene Lake, where the water was renewed by opening heavy flood gates in a massive sluiceway projecting into the sea. Here, as at Lake Fusaro, oysters were grown on fascines and fattened in baskets.

Oysters were cultured in ponds in Holland and Belgium for many years (Dean, 1893). In Holland the ponds were used mainly for growing seed oysters, but in Belgium oysters were fattened for the market in ponds.

In a unique method of pond culture in Norway, oysters are suspended in wire cages at mid-depths because the bottom water has no dissolved oxygen (Yonge, 1960). Spawning occurs here, and the larvae attach to branches that have been interlocked in wire netting. Mortalities can be high if the bottom and middle layers of water mix.

France has probably developed pond culture of oysters further than other European countries. Small oysters, "caught" on roofing tiles, are placed in tidal ponds. Just prior to marketing they are transferred to special rectangular basins (50 by 150 feet) called *claires,* where the oysters attain a creamy consistency and the gills acquire a highly prized green color. Oysters in claires may double their weight in 6 months (Yonge, 1960).

Dean (1892) described the production of seed oysters in a pond in France. The pond was drained and the bottom allowed to dry for 2 months, supposedly to kill animal and plant life. It was then filled, and mature oysters were stocked at the rate of about 40 per square yard. The outlet and inlet of the pond were blocked to trap the larvae soon after the oysters had spawned. An excellent set was caught on tiles placed on the bottom. Unfortunately, it is not known how successful this method was in later years.

The United States appears to be at least 100 years behind European countries in the development of oyster culture in ponds. The commercial use of ponds has been very limited, even though pond culture could be practiced in many areas along the East Coast.

Several experiments have been conducted in the United States to develop the pond culture of oysters. One of the first was on the shore of Chincoteague Bay, Md. (Ryder, 1883). A 50-square-yard pond was excavated in a salt marsh and connected to a bay by a trench 10 feet long, 2 feet wide, and 3½ feet deep. A set of oysters from ¼ to ¾ inch long was observed 46 days after fertilized eggs were placed in the pond. The experiment proved, in Ryder's estimation, that ponds or enclosed areas of water may be used readily for culturing oysters along the eastern coast of the United States. Lunz (1956) studied the culture of oysters in small ponds at Wadmalow Island, S. C. The studies were terminated after heavy mortalities, believed to have been caused by a fungus, *Dermocystidium*. Carriker (1959) made extensive studies on the culture of oysters and clams in Home Pond, Gardiners Island, Long Island Sound, N. Y. He concluded, "that utilization of salt-water ponds for the cultivation of such benthic species as oysters and *Venus* on a large scale is feasible; predictable success, however, must be predicated upon further extensive basic research." Loosanoff (1956) wrote that growing oysters in ponds has the advantage that they are protected from storms, and the control of enemies is feasible. The results and opinions of these investigators indicate that the pond culture of oysters in the United States does have a commercial potential.

Basic research on the culture of oysters in tidal ponds was initiated by the Bureau of Commercial Fisheries in 1956 at Chatham, Mass. Seed oysters strung on galvanized wire (Figure 1) were suspended from a log raft moored in Oyster Pond River from spring through fall, and in Oyster Pond during the winter. Attempts to grow small oysters on the bottom had failed in this area because of predation by drills and whelks.

The suspended oysters grew rapidly; average shell height was slightly over 2½ inches after only 1 year. At the end of 2 years the height of 75 percent of the oysters was more than 3 inches, the legal market size in Massachusetts. Marketable size thus was attained in 2 years by suspending oysters off the bottom, whereas 3 to 4 years normally are required for seed oysters to reach marketable size in New England when they are grown on the bottom. Mortality was low because the raft-grown oysters were not preyed upon by drills and whelks. The development of raft-grown oysters in the tidal ponds of Cape Cod appeared to be commercially feasible (Shaw, 1962).

Further studies were conducted in Taylors Pond, West Chatham, Mass. The growth of four strains of oysters was compared (Shaw and McCann, 1963), and seasonal changes in condition (fatness) of suspended oysters were measured (Shaw, 1963). These experiments

showed that certain strains of oysters grew faster than others and that suspending oysters off the bottom greatly improved their condition. Thus, an oyster of superior quality, suitable for serving on the half-shell, can be grown commercially in the tidal ponds of New England by off-bottom culture techniques.

For the past 4 years, a private company at Fishers Island, N. Y., has produced large quantities of seed oysters. Each spring the outlet of a 28-acre pond was blocked off during the spawning season to trap oyster larvae. A total of 25,000 7-foot strings, to which bay scallop shells were attached, were suspended from 125 rafts to catch

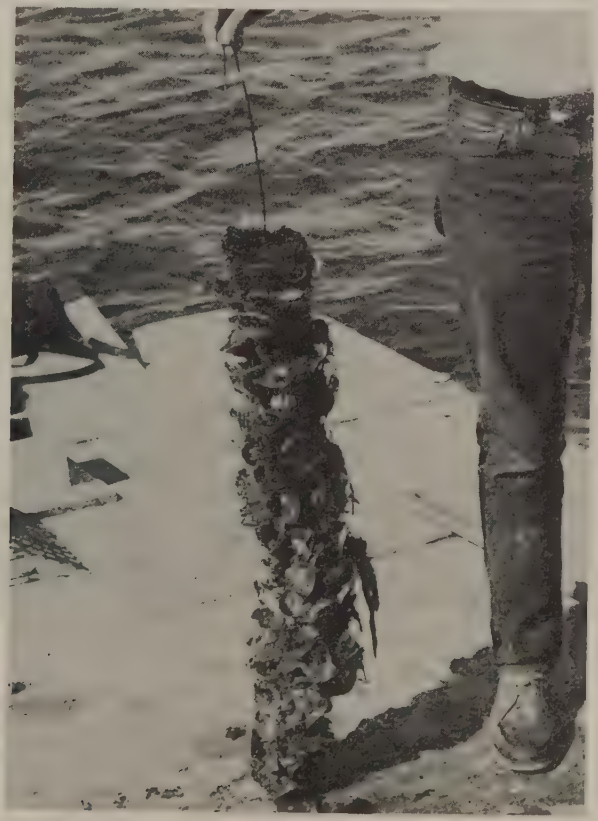

Figure 1. String of raft-grown oysters.

sets of oysters. In 1964, 10,000 bushels of seed oysters were harvested; an increase to 15,000 bushels is planned for 1965 (Binmore, 1964).

Extensive research on the culture of oysters in natural ponds is being carried on by the Bureau of Commercial Fisheries Biological Laboratory, Oxford, Md. In 1964 a rigid structure, 108 by 12 feet, was constructed in a tidal pond adjacent to the laboratory to test the feasibility of growing oysters commercially in tidal ponds of the Chesapeake Bay region. More than 1,000 strings of seed oysters were suspended from this structure (Figure 2) and 2,000 more are to be added in the fall of 1965. It is anticipated that a total of 1,500 bushels of oysters will be harvested from these strings after 2 years.

Figure 2. Strings of seed oysters attached to a wooden structure in a natural salt-water pond adjacent to the laboratory in Oxford, Md.

Beaven (1954) wrote that, "The use of small enclosed and artificially fertilized ponds for production of seed oysters might also be a possibility and would offer opportunity for experiments with selective brood stocks. Unfortunately facilities for this type of experiments are not now available in Maryland." This statement is no longer true.

Experiments are now in progress at the Oxford Laboratory on the

Figure 3. Four ¼-acre artificial, salt-water ponds located near the laboratory in Oxford. Pump house is in upper left hand corner and the Tred Avon River, source of water for ponds, in background.

culture of oysters in four ¼-acre artificial salt-water ponds (Figure 3). Water is pumped to each pond through a dual system at the rate of more than 80 gallons per minute. Baffles at the outlets of each pond control the water level to any desired depth below 3¼ feet. Environmental factors such as temperature, salinity, and amount of food organisms can be regulated to a considerable extent because large volumes of water can be exchanged readily (the ponds can be drained or filled within 24 hours).

In one pond seven strains of oysters from the seed producing areas of the Maryland portion of Chesapeake Bay are being studied for differential growth and survival. The shell size of each strain is measured periodically to determine growth rate. Strains that show fast growth can be used in future experiments on selective breeding.

In another pond, four types of bottom materials—clay, sand, oyster shell, and polyethylene film—are being tested to determine which is most suitable for growing oysters. Fifty bushels of oysters, averaging 2 to 3 inches in shell height, have been planted on each bottom type. Size, condition, and rate of survival are determined monthly.

Future plans include studies on the potential production of seed

oysters in artificial ponds by methods that have been successful in France (Dean, 1892) and at Fishers Island, N. Y. (Binmore, 1964). In addition, oyster larvae will be reared in the laboratory and released in the pond, where suitable collectors have been placed. Other future studies may include the development of techniques for fattening oysters, either by addition of fertilizer to increase phytoplankton production or by adding phytoplankton, grown in the laboratory, to the pond. The studies will be aimed at determining whether oysters can be cultured commercially in man-made ponds.

In a 1958 address to the National Shellfisheries Association, Paul S. Galtsoff stated, "The future welfare of the oyster industry calls for the solution of the following problems: reliable production of seed oysters; production of rapidly growing oysters with high-glycogen and high-solid contents; selection of disease resistant races; improvement of methods of self-purification of oysters; scientific evaluation or appraisal of oyster bottom based on their productivity capacity; and development of oyster pond culture in tidal marshes and other areas not used at present for oyster farming."

The recent pond studies in Massachusetts and Maryland are beginning to solve some of these problems, to attempt to help an industry whose landings have declined since the turn of the century. C. M. Yonge (1960) stated: ". . . the probability of a future for the oyster industry [will be] based largely on the results of intensive research at laboratories. . . ." This research is now being conducted at the Oxford Laboratory, not only to develop methods of pond culture, but also to determine what kills oysters, and to find methods to eradicate or control the causes of mortalities (Engle and Rosenfield, 1962). Similarly, intensive research on the commercial feasibility of culturing oyster larvae in hatcheries is being carried out at the Bureau's Biological Laboratory in Milford, Conn. (Loosanoff and Davis, 1963). It is unlikely that oysters ever will be as numerous as in the late 1800's, but it is hoped that this shellfish will again become sufficiently abundant to be removed from the category of a luxury food.

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DISCUSSION

DISCUSSION LEADER SCHONING: Thank you very much, Bill.

I noticed there are a number of commissioners and administrators in the audience and they always seem to be forever thinking about costs in operations. Therefore, I wonder if you would comment on the relative cost of the propagation of oysters as compared with present costs?

MR. SHAW: This was one of the first problems we had to look at, of course, the cost of culture. Immediately you lift the oyster off the bottom, you increase cost.

The first studies were done up on Cape Cod, Massachusetts, where the oysters at that time were sold for about $12.00 a bushel. From our early studies we found that the oysters we produced up in those waters was at a cost feasible to commercial growers. Now then, oysters are worth $16.00 a bushel in Massachusetts and so I think this method is even more feasible than back in 1960.

I would say that the most difficult problem here is that you are starting from scratch. You have to put out considerable money and then you have to wait at least two years or even three years before you realize any profit. This is sometimes discouraging to many oyster growers or the oyster industry.

CHAIRMAN LAWRENCE: I would like to ask for a little elucidation of your comment on the green colored oysters—whether they are not marketable because of taste or whether there is some real reason. I would like to mention also that I purchased a bushel of oysters this past week and quite a few were green and I was told by the oyster authority this was as the result of copper in the water. At any rate, I ate them, enjoyed them and thus far have not suffered any ill effects.

MR. SHAW: Well, this green coloring can be related to copper—this is true. However, this is not the case in France and was not the case in the incident I reported.

The green color is basically found in the gills of the oyster and comes from what the oyster is eating. For example, an individual out in Chesapeake Bay sent me a sample of oysters and wanted to know what the green coloring was and we summarized that it was due to material in the water that it was eating at that time. This individual further commented that because of his green coloring he had no market for the oyster.

Chesapeake Science Vol. 6, No. 1, pp. 33–37 March, 1965

Seasonal Setting Patterns of Five Species of Bivalves in the Tred Avon River, Maryland

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ABSTRACT: Bottle collectors were placed in the Tred Avon River, Maryland, during 1961, 1962, and 1963, to obtain information on the setting of bivalves. The bottle collector was an economical and efficient tool for obtaining and studying newly metamorphosed invertebrates in shallow estuarine waters. Seven bivalve species were caught on or in these bottles and the seasonal setting patterns of five species were observed. Of these species, *Mya arenaria* and *Macoma balthica* appeared to have dual spawning cycles each year, while *Brachidontes recurvus*, *Macoma phenax*, and *Mulinia lateralis* had a single annual spawning cycle.

Introduction

Since 1961, the U. S. Fish and Wildlife Service, Bureau of Commercial Fisheries Biological Laboratory at Oxford, Maryland, has been using the bottle collector (Thorson, 1946) to observe the seasonal setting patterns of bivalves in the Tred Avon River, Maryland. The study is part of an ecological investigation of the local fauna in the river and its relationship to commercial shellfish. This note reports the results of examinations of bottles for metamorphosed bivalves and gives a summary of the setting of five species collected over a period from 1961 to 1963.

Materials and Methods

The collector (Fig. 1) used was similar to that originated by Thorson (1946) except for two modifications: (1) a one-gallon glass syrup jug with the bottom removed replaced the "exsiccator-bottle," and (2) "Styrofoam" floats, 1 by 6 inches, were secured around the jug with stainless steel wire, instead of cork held in place with netting.

The bottles were placed in water approximately 2 feet off the bottom. A small wooden buoy at the surface marked the location of the collector; a large "Styrofoam" float halfway between the water surface and the bottle kept the collector upright and prevented rolling during rough weather. One-half of a cement block was used as an anchor.

Single collectors were placed at each of four stations in the Tred Avon River (Fig. 2) and were replaced, on the average, every 30 days. A longer period of exposure resulted in excess siltation and overgrowth of diatoms, whereas shorter periods on station did not allow sufficient growth of bivalves to permit positive identification. Sampling was conducted from 28 June to 7 December 1961, 11 April to 13 November 1962, and 1 April to 24 September 1963.

The contents of each bottle were poured into either a No. 80 (.0070 inch opening) or a No. 60 (.0098 inch opening) sieve. Prior to examination under a dissecting microscope, the sieve was flushed with sea water to remove silt and detritus. Metamorphosed bivalves were then identified and counted. In addition, the outer surfaces of each bottle and the floats around it were examined for bivalves. Seasonal setting patterns were determined by combining the data collected from all four stations in the river.

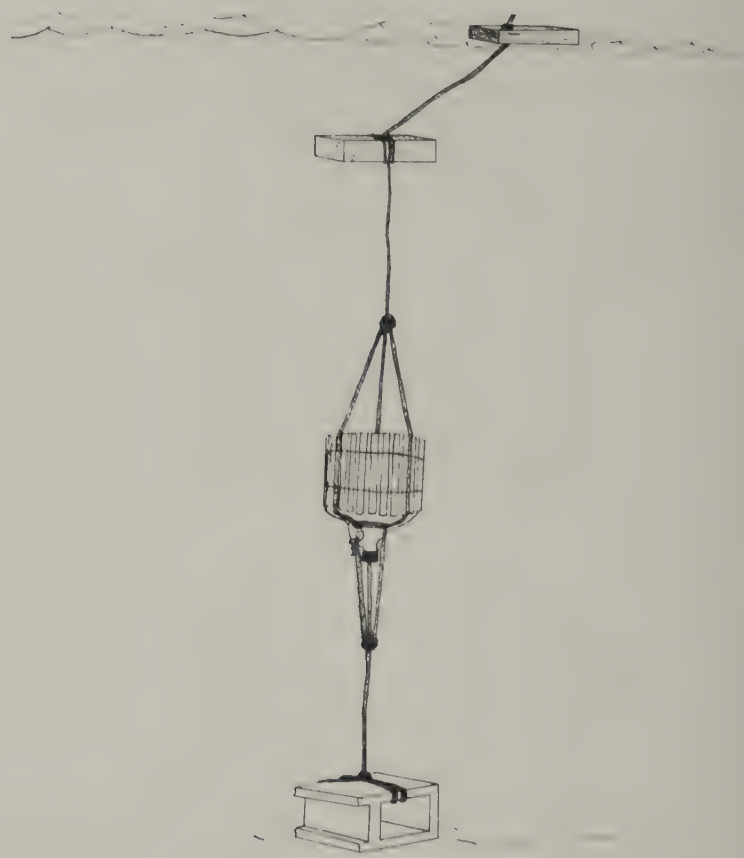

Fig. 1. The bottle collector. After Thorson (1946).

Results

Seven species of bivalves were caught on or in the bottles during the study; these were: *Amygdalum papyria, Congeria leucophaeta, Brachidontes recurvus, Macoma balthica, Macoma phenax, Mulinia lateralis,* and *Mya arenaria.* The latter five were caught in sufficient numbers to permit determination of seasonal setting patterns (Fig. 3).

During the periods of observation, *Brachidontes recurvus* and *Macoma phenax* were present on or in the collectors from April to December. *Mulinia lateralis* was not observed in early spring, but was first observed in bottles set out in May and continued to be found throughout the year into November. All three species appeared to have a continuous period of setting with no apparent gaps during the spawning season.

On the other hand, *Mya arenaria* and *Macoma balthica* were found to have biannual spawning seasons. A summary of the data shows that *Mya* was found in bottles from August to December. It was also in bottles out from 7 May to 17 June 1963. However, no *Mya* were ever found during the periods of observation from July to late August. Furthermore, none were found in the spring of 1961 and 1962.

During the three-year study, *Macoma balthica* was observed in bottles placed in the river from April to June and again from

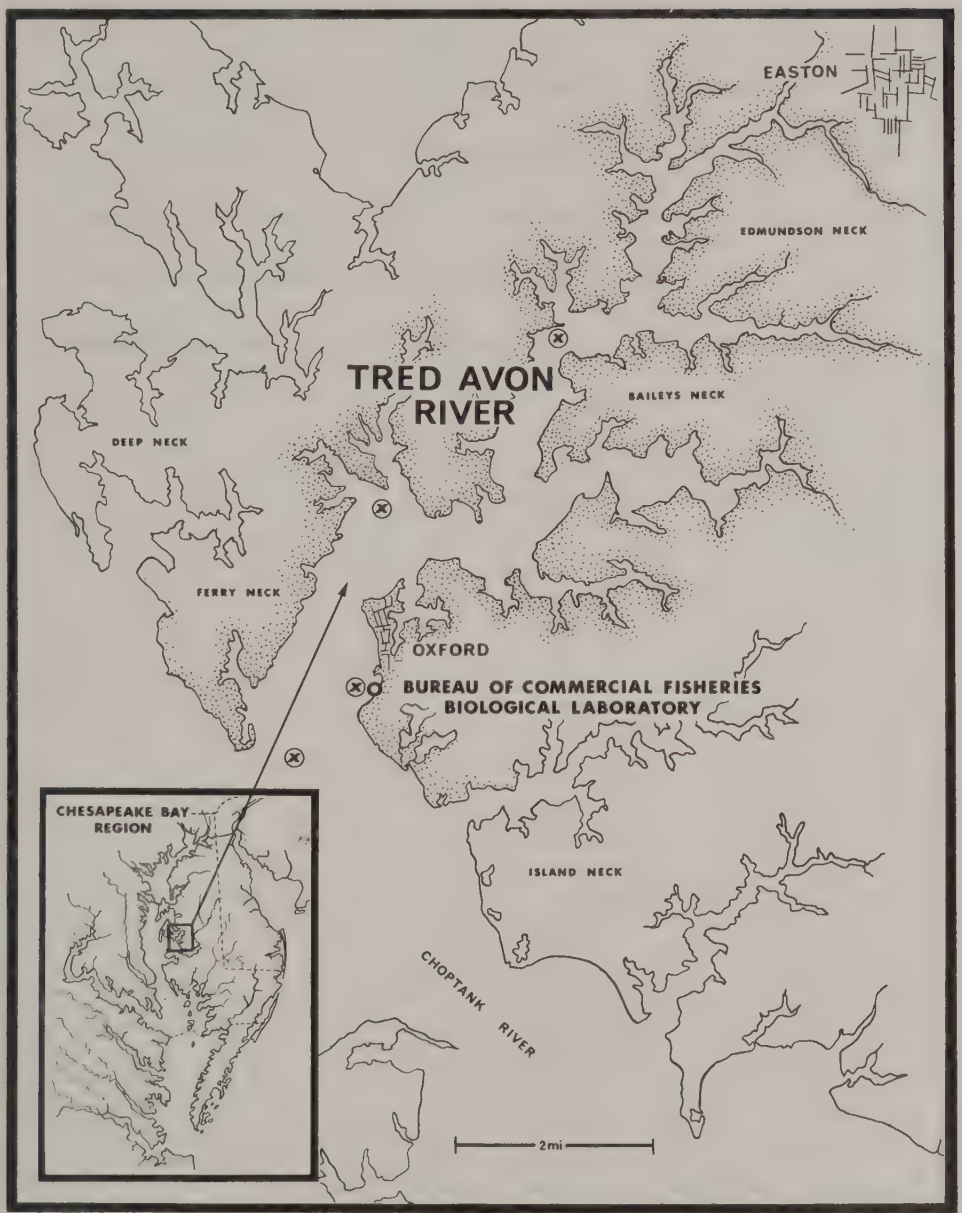

Fig. 2. Bottle collector stations, designated by circled X's, in the Tred Avon River, Maryland.

August to November. Based on the numbers of *M. balthica* found in the collectors, setting seems to be greater in the spring than in the fall. No *M. balthica* were found in any of the bottles between late June and late August indicating, as in the case of *Mya*, two distinct spawning periods each year.

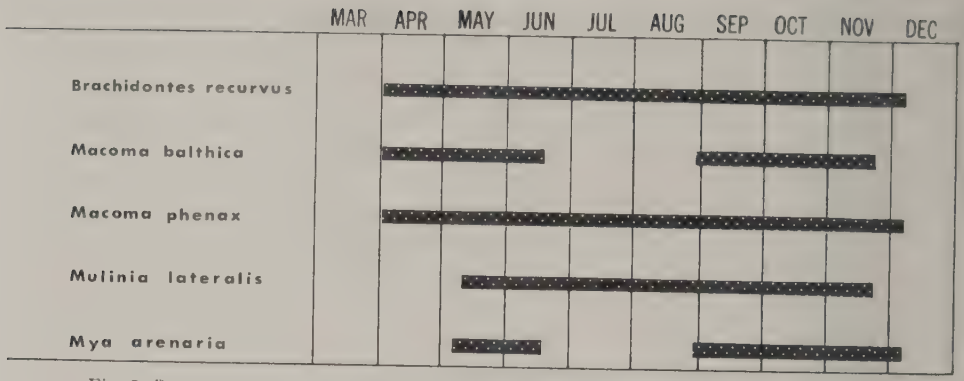

Fig. 3. Summary of occurrence of bivalves collected by bottles in Tred Avon River.

It is interesting to mention that no eastern oysters, *Crassostrea virginica*, were caught on or in the bottles during the three-year study, although several did set on the cement blocks. However, monitoring of the Tred Avon River by the Oxford Laboratory since 1960 revealed that this river has little oyster setting.

Discussion

The periods of setting determined by this study for several of the species listed in Figure 3, such as *B. recurvus*, do not preclude the possibility that setting could have begun earlier than April and extended beyond the first week in December. However, progressively lighter setting of these species was observed into December, suggesting that spawning is reduced or ceases during the winter periods. Allen (1962) found that the spawning of *B. recurvus* at Hackett's Bar, located on the Western Shore of Chesapeake Bay, lasted from June until November, or a period somewhat shorter than that observed in this study.

Since only 5 specimens of *Mya* were found in the spring of 1963 and none in the spring of 1961 and 1962, it appears that setting of *Mya* during this period is markedly limited in the Tred Avon River. Pfitzenmeyer (1962) reported that *M. arenaria* was collected in May and June 1957, 1958, and 1959 at Solomons, Maryland, which indicates a more regular spring setting pattern for this species on the Western Shore as compared with that found on the Eastern Shore of Chesapeake Bay.

The bottle collector is an excellent tool for trapping bivalves but does not necessarily indicate the entire endemic fauna of an area. It is possible that some species caught on or in the bottle would not be found in the area because of setting failures, unsuitable surface on the bottom for setting, or because the larvae were transported by tidal flushing. According to Carriker (1961) the collectors are possible attractors for larvae because of the gradients of turbulence around them. At the same time, sediments are collecting in the bottom of the bottle, providing suitable habitat for setting larvae. Those species, like the mussels, which do not set in the sediments, have the bottle or its floats on which to attach.

Since the collector is 2 feet off the bottom, those species of bivalves, for example *M. arenaria*, that migrate or crawl during their early stages of life after setting (Smith, 1955), cannot get into the collector via migration. Unless a close watch is made on setting on the natural substrate, false setting patterns for species like *Mya* could be obtained if the collector were on the bottom.

Dual spawning cycles have been found by Landers (1954), Pfitzenmeyer (1962), and Shaw (1964) for *Mya arenaria*. It appears that *Macoma balthica* also exhibits this phenomenon while the other three

species have a single annual spawning season much like that of the eastern oyster, *C. virginica* (Loosanoff, 1943) and the quahog, *Mercenaria mercenaria* (Loosanoff, 1937). Though the setting of *M. arenaria* and *M. balthica* in bottles during two distinct periods of the year strongly suggests a split spawning season, only by careful histological examination of the gonad can this pattern be verified.

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E-6

SEASONAL AND AREAL DISTRIBUTION OF GULF OF MAINE COASTAL ZOOPLANKTON, 1963

By

Kenneth Sherman[1]

ABSTRACT

Gulf of Maine coastal waters were sampled for zooplankton on single cruises during the winter, spring, summer and fall, 1963. Areal and seasonal variations were found in zooplankton volumes, major group occurrences and species composition. Three areas - the western, central and eastern Gulf - showed differing patterns of relative zooplankton abundance, with highest volumes occurring in the western sector, moderate volumes in the central area and lowest volumes in the eastern area.

Major zooplankton groups were more numerous in the western Gulf during winter, spring and fall. In summer, zooplankton groups were found in a variable pattern throughout each of the sampling areas. Larval forms were most numerous during spring and summer, indicating widespread breeding during these periods.

Copepods were the most numerous group of zooplankters encountered. Twenty-two species were present of which eight - *Calanus finmarchicus, Centropages typicus, Metridia lucens, Pseudocalanus minutus, Acartia longiremis, Oithona similis, Temora longicornis,* and *Tortanus discaudatus* - were most numerous. Six species were more abundant in the western area then in the eastern sector during all seasons. *Calanus finmarchicus* was more abundant in the east than the west in spring and *P. minutus* reached maximum numbers in the central area during summer. The fluctuations in seasonal and areal distribution of zooplankton volumes, major groups, and species are discussed in relation to previous studies and possible causes of variation.

INTRODUCTION

As part of a research program on the relation between environmental factors and availability of immature herring, *Clupea harengus* L., the Bureau of Commercial Fisheries Biological Laboratory, Boothbay Harbor, Maine, initiated a study of the Gulf of Maine coastal zooplankton. Research has provided information regarding seasonal and annual changes in zooplankton distribution and abundance.

In his classic work, Bigelow (1926) was first to describe the Gulf of Maine zooplankton. He characterized the dominant forms as the "Calanus Community" and showed that this endemic assemblage of zooplankters underwent seasonal pulsations in standing crop, progressing from a winter minimum to a spring-summer maximum, and was augmented annually by intrusions of northern and southern immigrant forms. Subsequent studies of Fish and Johnson (1937) and Redfield (1941) acknowledged the permanence of Bigelow's calanoid community, and the occurrence of immigrant species. Reports on endemic copepod species have been published by Fish (1936*a*, *Calanus finmarchicus;* 1936*b* *Pseudocalanus minutus;* 1936*c* *Oithona similis;* 1955 *Microstella norvegica*) and Redfield (1941, Calanoid species). Information regarding immigrant zooplankters was presented by Redfield (1939) for populations of the pteropod *Limacina retroversa* and by Redfield and Beale (1940) for several chaetognath species. Recently, Colton, *et al.* (1962) reported on the periodic intrusions of oceanic copepods into the inner reaches of the Gulf.

In the earlier works of Bigelow (1926) and Fish and Johnson (1937), lower mean-annual-volumes of zooplankton were reported east of the centrally located Penobscot Bay area than to the west of this region. Recent information, provided by staff members of the Boothbay Harbor Laboratory, suggests that this difference in areal distribution along the Maine coast is not limited to zooplankton. During 1962, it was observed that mean length of two-year-old herring was greater in the area west of Penobscot Bay than to the eastward (Watson, J.E., unpublished data). Erythrocyte antigen frequencies

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of young herring were found to differ east and west of Penobscot Bay (Sindermann, 1962). A discontinuity of the myxosporidian parasite, *Kudoa clupeidae*, was observed in small herring with infestations occurring west of Penobscot Bay but not to the eastward (Sindermann, 1961). Also, differences in spawning time of herring occur east and west of Penobscot Bay, as evidenced by the occurrence of larvae (≤ 9 mm standard length) east of Penobscot Bay two to three weeks earlier than larvae of the same size found to the westward (Graham, J.J., personal communication). In view of these findings, sampling was undertaken to determine whether differences in the composition and relative abundance of zooplankters occurred along the Maine coast.

METHODS

This report is based on the examination of 71 zooplankton samples collected from Gulf of Maine coastal waters during four seasonal cruises of the research vessel, *Rorqual*. Station locations and periods of collection are given in Table 1. Zooplankton samples were collected with a Gulf III sampler

TABLE 1. STATION LOCATIONS AND PERIODS OF COASTAL ZOOPLANKTON COLLECTIONS, *Rorqual* CRUISES 1, 4, 5 AND 7, 1963.

Station number	Position		Sampling periods, 1963			
	Lat.	Long.	*Rorqual* 1 5-16 Jan.	*Rorqual* 4 25 May- 2 June	*Rorqual* 5 10-22 July	*Rorqual* 7 11-20 Oct.
1.	42°43'	70°30'	X	X	X	X
2.	42°51'	70°43'	X	X	X	X
3.	42°56'	70°41'		X	X	X
4.	43°08'	70°23'		X	X	X
5.	43°17'	70°30'	X	X	X	X
6.	43°24'	70°12'		X	X	X
7.	43°39'	70°09'		X	X	X
8.	43°35'	69°52'	X	X	X	X
9.	43°42'	69°42'			X	X
10.	43°48'	69°29'	X	X	X	X
11.	43°51'	69°26'		X	X	X
12.	43°46'	69°06'	X	X	X	X
13.	43°48'	68°47'		X	X	X
14.	43°57'	68°93'	X	X	X	X
15.	44°02'	68°14'	X	X	X	X
16.	44°17'	68°07'	X	X	X	X
17.	44°10'	67°53'	X	X	X	X
18.	44°27'	67°50'		X	X	X
19.	44°27'	67°18'	X	X	X	X
21.	44°34'	67°19'	X	X	X	X
Number of stations sampled			12	19	20	20

Gehringer, 1962), fitted with an eight-inch nose cone and monel netting (aperture width 0.37 mm). All tows were of 30-min duration, taken during daylight hours, from 20 m to the surface in an oblique manner, with 10 min of towing at the surface and at depths of 10 and 20 m. A calibrated flow meter, affixed to the tail section of the Gulf III, was used to determine the amount of water strained. In addition, a U.S. Navy Electromagnetic Underwater Log, mounted on the keel of the *Rorqual*, measured the distance traversed during each tow. Analyses of the variation in the amount of water strained as determined by meter readings and Electromagnetic Log values indicated no significant differences in amount of water strained (Graham, J.J., unpublished data). For cruises 1 and 7, meter readings were used to calculate the amount of water strained, and for cruises 4 and 5, Electromagnetic Log readings were used. The average 30-min tow covered a distance of three nautical miles and filtered approximately 200 m^3 of water. Towing speed was maintained at approximately 6 knots.

In the laboratory, displacement volumes of all samples were taken. Ctenophores, large coelentrate remains (>2 cm long), and all fish larvae were removed from the samples and not included in the final volume determinations. Samples containing large quantities of ctenophores and medusae were not included in the analyses, due to the filtration error introduced by mesh clogging. Zooplankton samples were split into aliquots ranging from a half to a sixty-fourth, depending on the mass of the sample, and sorted into major taxonomic groups. Copepods were identified to species and the numbers of copepods and other zooplankters, per 100 m^3 of water strained were calculated.

RESULTS

Zooplankton Volumes

Seasonal and areal distributions of zooplankton volumes were compared. Abundance estimates are considered to be minimal, as use of a 0.37 mm mesh aperture limited sampling to the larger zooplankters. Also, tows were limited to the upper 20 m, and were taken only during daylight hours. To examine differences in areal distribution, the coastal region was divided into three areas, a central area located in the vicinity of Penobscot Bay, an eastern area extending from Mt. Desert Island to Grand Manan Island, and a western area from Casco Bay to Cape Ann. The areas, station locations, and sampling periods are shown in Fig. 1.

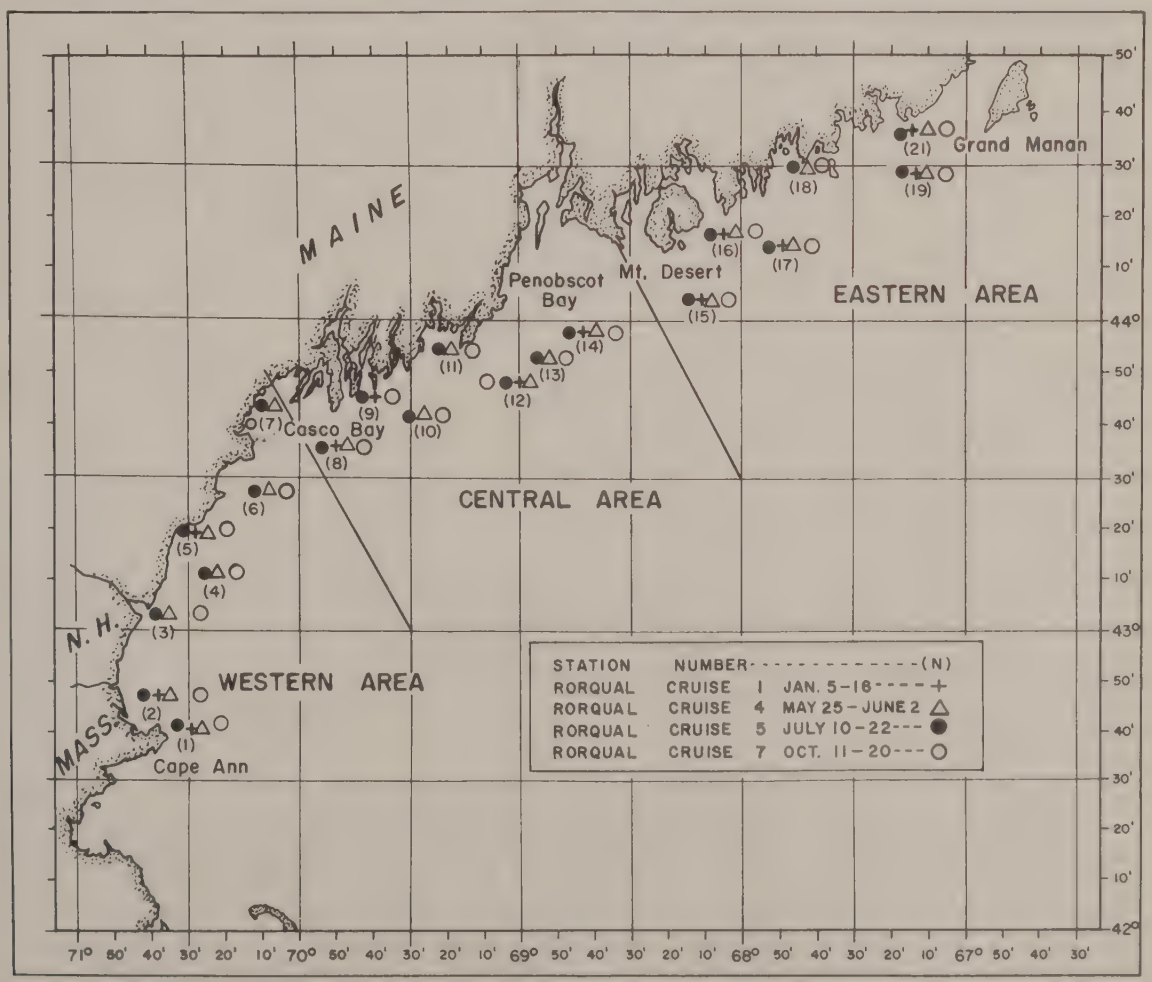

Fig. 1. Zooplankton sampling areas, station locations and periods of collections.

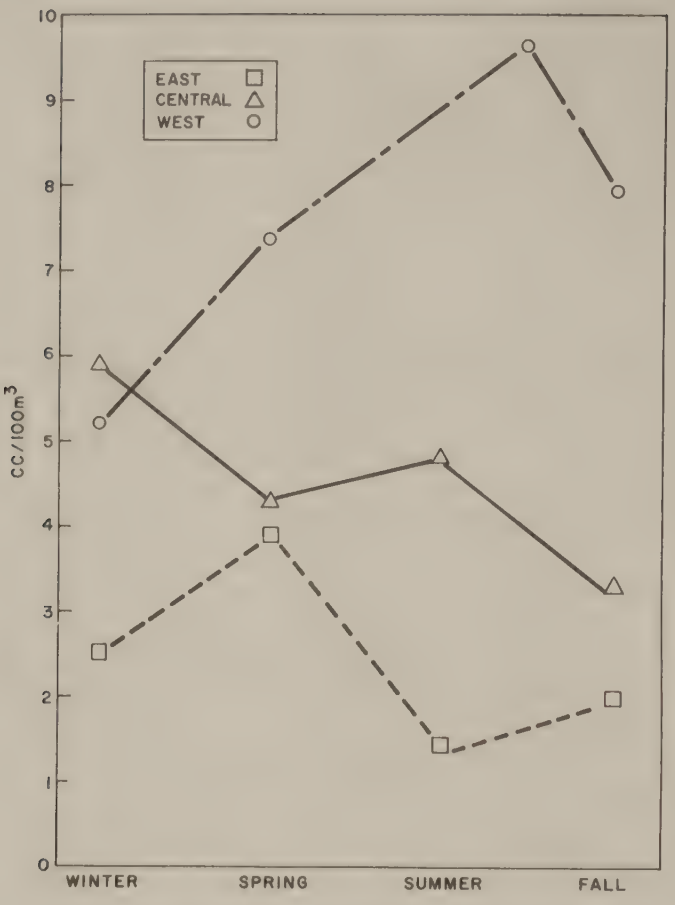

Fig. 2. A comparison of average zooplankton volumes per 100 m^3 of water strained among seasons for each of the three areas.

A comparison of average zooplankton volumes among areas for each of the four seasons is given in Fig. 2. Significant differences among areas ($H=19.159$, $P<.01$) were found using the Kruskal-Wallis analysis of variance (Siegel, 1956). In the eastern area the displacement volumes were the lowest encountered, ranging from a spring high of 3.9 cc/100 m^3 to a summer low of 1.4 cc/100 m^3. An intermediate range of values was found in the central area, ranging from a winter high of 5.9 cc/100 m^3, to a fall low of 3.2 cc/100 m^3. The greatest seasonal change in mean volumes occurred in the western area with values progressing from a winter low of 5.2 cc/100 m^3 to a summer high of 9.6 cc/100 m^3.

Zooplankton Groups

The percentage composition of the zooplankton groups encountered on each of the seasonal cruises is presented in Fig. 3. Copepods were the dominant zooplankters during each of the seasons, reaching a fall and winter high of 91% of the total zooplankton and declining to 45% in summer. Of the other planktonic forms found, ninepteropods, chaetognaths, decapod larvae, cladocerans, brachyuran larvae, tunicates (appendicularians), cirripeds, and fish and crustacean eggs--constituted greater than 1% of the total zooplankton. The spring and summer decline in percentage composition of copepods was associated with the increase of other abundant (> 1% of the total zooplankton) groups; from two in winter to five in spring and seven in summer (Fig. 3). The breeding period of many species during warmer months was evidenced by the abrupt rise in decapod larvae in spring, and fish eggs and crustacean eggs during summer. Cirripeds occurred in swarms during spring, but diminished in summer with the onset of substrate attachment. Brachyuran and pelecypod larvae occurred during the summer and fall periods only. The fall decrease in the number of abundant zooplankton groups present indicated that the zooplankton population was approaching the winter minimum.

To examine the areal distribution of the dominant zooplankton groups, the mean number of zooplankters per 100 m^3 of water was determined for each of the three areas and for each of the seasonal cruises. Differences in areal distribution were plotted for major groups only (>100/100 m^3). During the winter period, copepods were the dominant zooplankters in all areas (Fig. 4A), but were more numerous in the western than in the eastern area.

In spring as in winter, copepods were the dominant zooplankters, increasing in numbers from a group mean of 645/100 m^3 in winter to 5,575/100 m^3 in spring (Fig. 4B). The spring rise in copepods was accompanied by increases in numbers of other major groups - decapod larvae, cladocerans, pteropods, cirriped larvae and tunicates. All major groups, with the exception of cirriped larvae, decreased in numbers from west to east (Fig. 4B).

An increase in the number of major groups was evident during the summer period (Fig. 4C). As in the preceding two seasons, copepods were the dominant zooplankters, with the grestest number (9,853/100 m^3) present in the western sector. Decapod and brachyuran larvae were also more numerous in the western area than in the east. The central area was characterized by a number of dominant

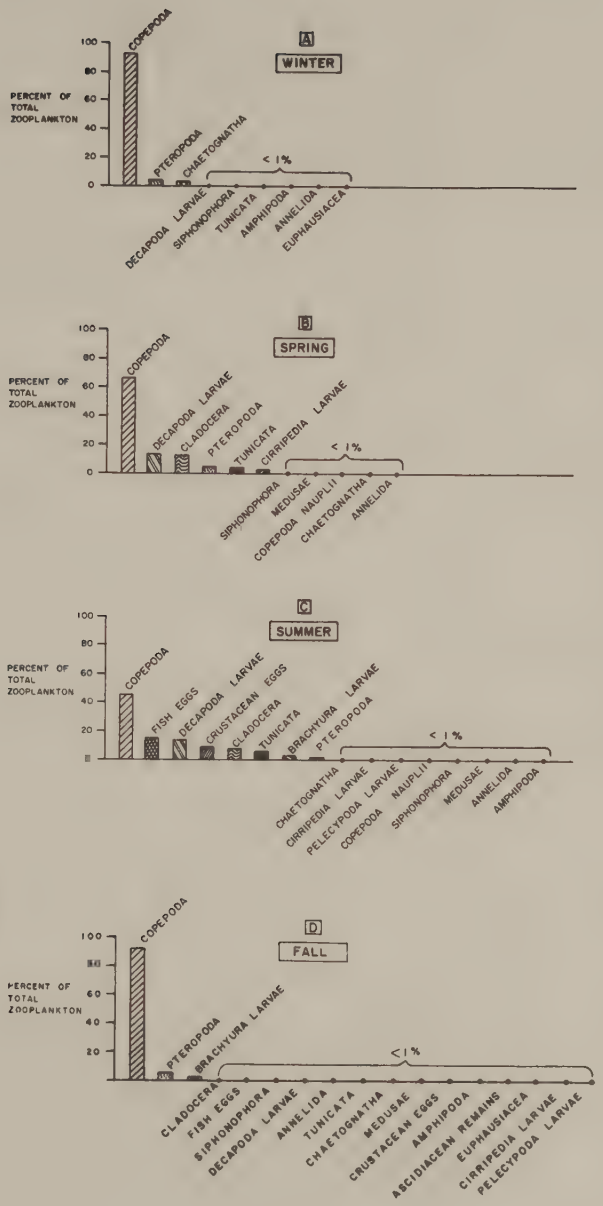

Fig. 3. Percentage composition of the zooplankton groups encountered on each of the seasonal cruises.

forms; cladocerans, pteropods, chaetognaths and fish eggs. Tunicates and crustacean eggs were more numerous in the eastern area.

During fall, fewer major groups of zooplankters were found than in summer, with a reduction from nine to four (Fig. 4D). Fish and crustacean eggs were also markedly reduced in numbers, from a summer high of 4,625/100 m^3 and 2,721/100 m^3, respectively, to less than 100/100 m^3. As in the preceding seasons, copepods were the dominant zooplankters in all areas, with the greatest number

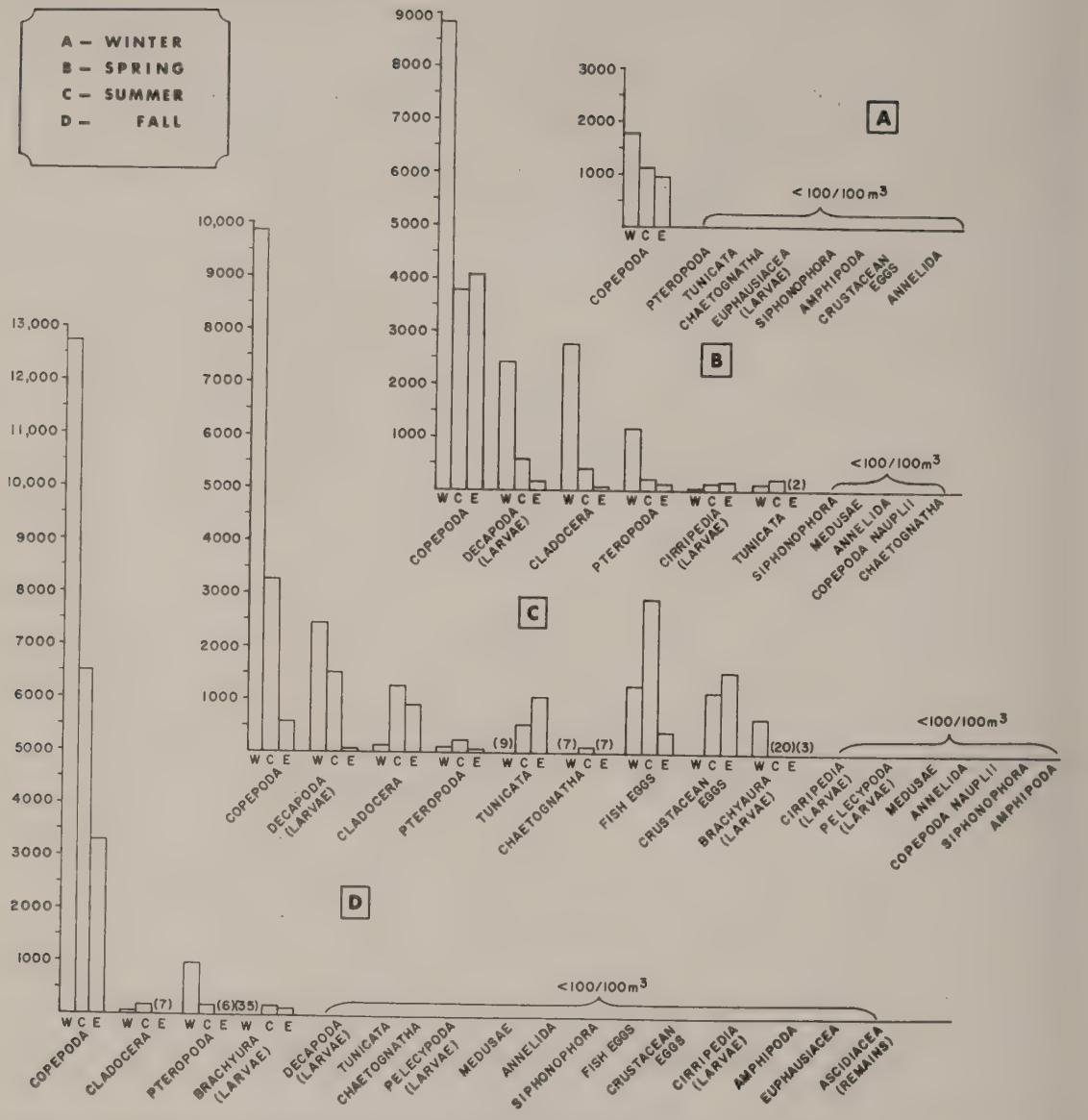

Fig. 4. Bar graph represents the mean number per 100 m^3 of water strained of the dominant zooplankton groups present in each of the three areas-west, central and east-during winter, spring, summer and fall.

(12,744/100 m^3) occurring in the western sector. Other groups more numerous in the western than in the eastern area were cladocera and pteropods. Of the four major groups, only one, brachyuran larvae, was more numerous in the central area. The low abundance of fish eggs, crustacean eggs, and larvae of other groups, indicated that the widespread breeding, characteristic of the summer period, was over and that the zooplankton population was approaching the winter minimum.

Copepod Species Occurrence

Copepods were the dominant zooplankters during all seasons. Species encountered are listed in Table 2. They have been arranged into two groupings; the common forms, those species exceeding

TABLE 2. COPEPOD SPECIES ENCOUNTERED DURING THE 1963 ZOOPLANKTON SAMPLING.

	Mean number/100 m^3	
	Common species >50/100 m^3	Less numerous species <50/100 m^3
Acartia longiremis (Lilljeborg)	204	
Calanus finmarchicus (Gunnerus)	1446	
Centropages typicus Kroyer	2308	
Metridia lucens Boeck	411	
Oithona similis Claus	141	
Pseudocalanus minutus (Kroyer)	398	
Temora longicornis (Muller)	160	
Tortanus discaudatus (Thomson and Scott)	76	
Acartia clausi Giesbrecht		3.17
Aetidius armatus Boeck		0.197
Calanus hyperboreas Kroyer		0.70
Candacia armata (Boeck)		3.21
Centropages hamatus (Lilljeborg)		0.704
Euchaeta norvegica Boeck		0.845
Eurytemora sp.		2.51
Oithona plumifera Baird		0.113
Oithona spinirostris Claus		23.00
Pleuromamma robusta (Dahl)		0.028
Pleuromamma xiphias Giesbrecht		0.028
Rhincalanus nasutus Giesbrecht		0.098
Scolecithricella minor Brady		0.042

a mean value of 50/100 m^3 for all cruises, and the less numerous species, with a mean value of <50/100 m^3 for all cruises. Of the eight common species, *Centropages typicus* was the dominant copepod, followed by *Calanus finmarchicus, Metridia lucens, Pseudocalanus minutus, Acartia longiremis, Temora longicornis, Oithona similis* and *Tortanus discaudatus* (Fig. 5).

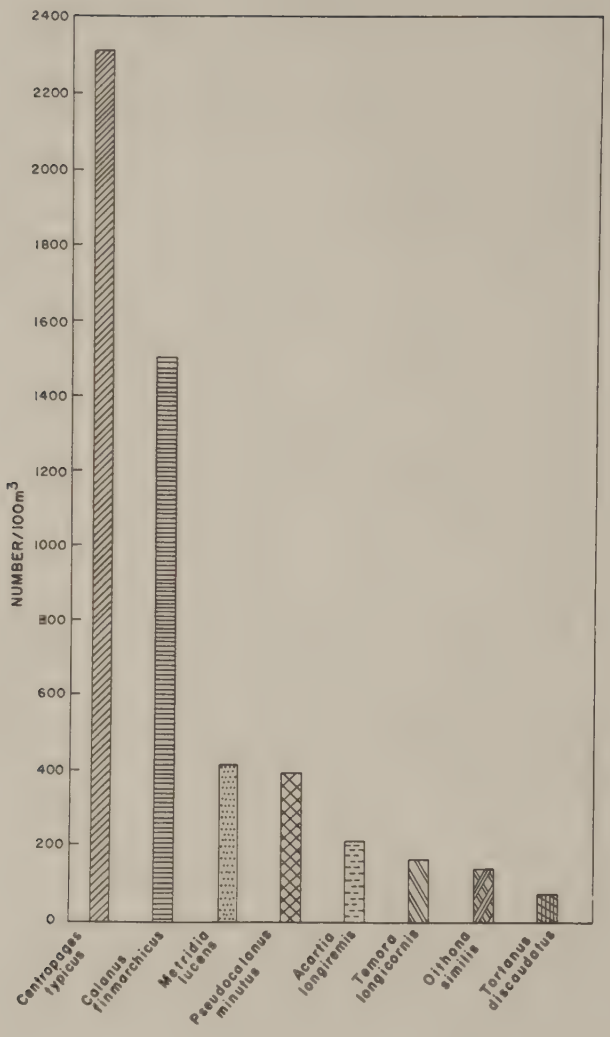

Fig. 5. Bar graph represents the mean number per 100 m^3 of water strained of eight commonly occurring copepod species during 1963.

Six of the eight commonly occurring species declined in abundance from west to east during all seasons (Fig. 6A to F). Differing patterns of occurrence were shown by two species, *C. finmarchicus*, and *P. minutus*, with the former species more abundant in the eastern area than in the western sector during spring and the latter reaching maximum numbers in the central area during summer (Fig. 6G and H).

Seasonal variability in species occurrence was observed among the eight common species. Five reached peak numbers in summer; *C. finmarchicus, M. lucens, O. similis, P. minutus* and *T. discaudatus* Of the remaining three, *A. longiremis* was most numerous during spring, and *C. typicus* and *T. longicornis* reached peak numbers in the fall (Table 3).

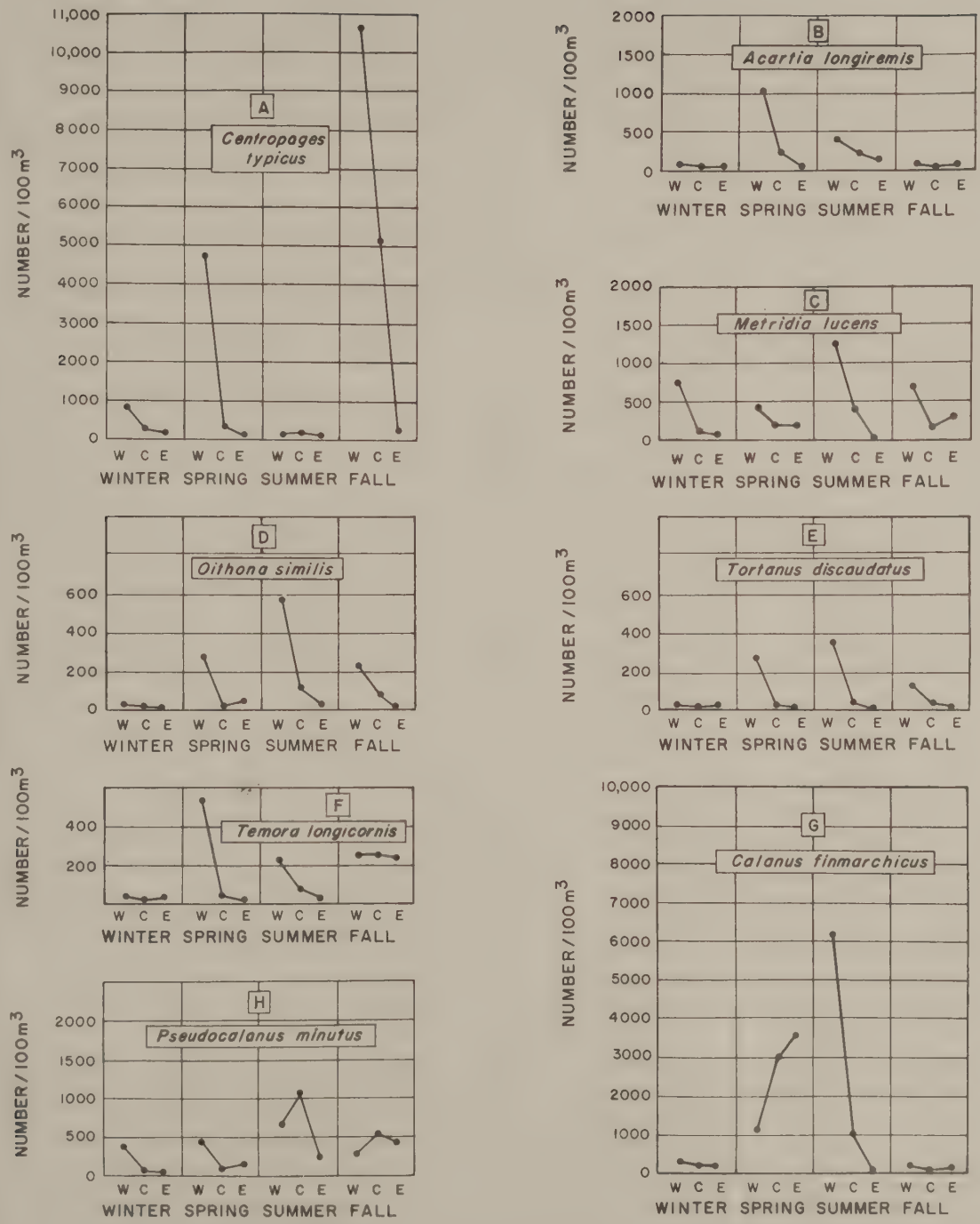

Fig. 6. The areal and seasonal variation in numbers per 100 m^3 of water strained of the eight commonly occurring copepod species.

TABLE 3. SEASONAL PERIODS OF MAXIMUM ABUNDANCE OF THE COMMONLY OCCURRING COPEPOD SPECIES.

Species	Winter 5-16 Jan.	Spring 25 May-2 June	Summer 10-22 July	Fall 11-20 Oct.
Acartia longiremis		O		
Calanus finmarchicus			O	
Centropages typicus				O
Metridia lucens			O	
Oithona similis			O	
Pseudocalanus minutus			O	
Temora longicornis				O
Tortanus discaudatus			O	

TABLE 4. SEASONAL AND AREAL OCCURRENCE OF THE LESS NUMEROUS COPEPOD SPECIES.

Species	Winter (+)			Spring (O)			Summer (X)			Fall (Ø)		
	west	central	east	west	central	east	west	central	east	west	central	east
Aetidius armatus	+											
Acartia clausi				O		O				Ø		
Calanus hyperboreas			+									
Candacia armata	+	+	+						X	Ø		
Centropages hamatus				O						Ø		
Euchaeta norvegica		+								Ø		
Eurytemora sp.				O			X	X	X	Ø		
Metridia longa											Ø	Ø
Oithona plumifera					O							
Oithona spinirostris	+	+			O	O			X	Ø		
Pleuromamma robusta						O						
Pleuromamma xiphias			+									
Rhincalanus nasutus			+									
Scolecithricella minor								X				

The less common species presented interesting patterns of occurrence (Table 4). Of the 14 species found, 8 occurred only during a single season. In winter 4 species, considered to be oceanic in origin, were found - *Aetidius armatus*, *Calanus hyperboreas*, *Pleuromamma xiphias*, and *Rhincalanus masutus*. All but *A. armatus* occurred only in the eastern area. Other seasonally occurring species were: *Oithona plumifera*, and *Pleuromamma robusta*, present only during the spring, *Scolecithricella minor*, found in summer and *Metridia longa* present only in fall. Species occurring in more than a single season were: *Acartia clausi*, *Candacia armata*, *Centropages hamatus*, *Euchaeta norvegica*, *Eurytemora* sp. and *Oithona spinirostris*.

DISCUSSION

A comparison of mean displacement volumes for each of the areas and seasons revealed different patterns of abundance. The highest values for all seasons were found in the western area. The lowest values occurred in the eastern sector, and intermediate volumes in the central area. Based on data collected during the warmer months (April-October), Bigelow (1926), Fish and Johnson (1937) also found that the region west of Penobscot Bay was consistently higher in zooplankton volumes than the relatively "barren" area to the eastward, from Mt. Desert to the Bay of Fundy. The progression from a winter low to a summer high in the western area is also in agreement with Bigelow (1926); Fish and Johnson (1937) and Redfield (1941). In addition these authors have indicated a late summer reduction in volumes, followed by a short-lived fall increase. During 1963, this fall increase was not apparent in the western or central areas. However, a slight increase in zooplankton volumes occurred in the eastern area.

The seasonal variations of volumes in the central and eastern areas are not compatible with the findings of Bigelow (1926) or Fish and Johnson (1937). However, Redfield (1941) showed that the "Seguin" sector of the Gulf, an area comparable to the central area, had only moderate plankton volumes in summer which declined in fall, increased in winter, declined in spring and increased in summer. The present pattern of seasonal variability in volumes in the central area is in agreement with the description given by Redfield for 1933 data. The increase in volumes, however, from summer to fall of 1934, reported by Redfield (1941), indicated that annual variations can be expected in the central area. In the eastern area, the winter-spring increase in volumes although of a lesser magnitude than the western sector, is in agreement with previous reports. However, the summer decline observed in this region has not previously been reported. Future sampling is planned for this region to examine these results more closely.

Major zooplankton groups showed a seasonal variation both in numbers and areal distribution. Most of the groups were more numerous in the western sector than in the eastern. The most notable exceptions occurred during the summer period when six groups - cladocerans, pteropods, tunicates, chaetognaths, fish eggs and crustacean eggs - were more numerous in the central and eastern areas. The significance of this shift in areal distribution is not known. However, it was found that considerable breeding during the warmer months occurs in the northeastern sector of the Gulf of Maine eddy, as evidenced by the presence of large numbers of fish and crustacean eggs occurring in the central and eastern areas. The general southwesterly movement of surface waters in this eddy (Bigelow, 1926; Bumpus, 1960) may be one of the factors contributing to the concentration of zooplankton in the western area in the period succeeding the peak summer breeding.

Bigelow (1926): Fish and Johnson (1937) indicated that copepods were the most numerous and comprised the greatest volume of zooplankters occurring in Gulf of Maine waters. These investigators also found that volumes of zooplankton were consistently higher west of Penobscot Bay than east of this region. It would follow then, that most of the endemic copepod population would also decrease in abundance from west to east. Fish (1936 *a*, *c*) reported this decrease for the copepods *Calanus finmarchicus* and *Oithona similis* and noted two breeding stocks for each species - one located east of Penobscot Bay and the other, the principal breeding grounds, to the west.

The decrease in numbers from west to east of all but two species of the commonly occurring copepods found during the present study confirms the conclusions reached by earlier investigators. The apparent exceptions were the species, *Calanus finmarchicus* and *Pseudocalanus minutus*. In this regard, Fish (1936*a*) has shown that successive broods of *C. finmarchicus* produced in the western Gulf were transported initially to the outer Gulf and then to the inner reaches of the eastern and central areas by the upper waters of the Gulf of Maine eddy. These circulation features were thought to be the mechanism for transporting large numbers of *C. finmarchicus* to other areas of the Gulf from the principal western breeding area during spring and summer (Fish, 1936*a*). The large numbers of *C. finmarchicus* found in the eastern area during spring may have resulted from this type of current transport.

The large numbers of *Pseudocalanus minutus* found in the central area during summer is not entirely unexpected. Fish (1936*b*) reported the presence of three stocks of *P. minutus* for: 1) the outer Gulf, 2) the western coastal area, 3) the region east of Mt. Desert to the Bay of Fundy. He indicated that in early spring, the western brood became widely dispersed, and that in late summer, the larger part of the *P. minutus* population originated in waters of the outer Gulf. The presence of large numbers of *P. minutus* in the central area during late summer could have been related to the inshore movement of the Gulf of Maine eddy in this area during the late summer period. Copepod length frequency data could provide additional information regarding the origin of copepod populations and future effort will be directed toward providing this information.

Although occurring in relatively small numbers, immigrant zooplankton species have provided an insight into the origin and along-shore movements of the mixed waters of the Gulf of Maine eddy system (Bigelow, 1926; Fish and Johnson, 1937; Redfield, 1939, 1941; Colton, *et al.*, 1962). The presence of *Calanus hyperboreas*, *Pleuromamma xiphias*, and *Rhincalanus nasutus*, in the eastern area only during winter is in agreement with Redfield (1939, 1941), who reported the indraft of oceanic water from the Nova Scotian banks into the Gulf of Maine during winter.

In a discussion of the environmental characteristics of the Gulf of Maine, Bigelow (1927) concluded that the wide seasonal variations in temperatures of the Gulf are due to... "its geographic location to the leeward of the continent and to the vigorous land climate. Only in a much smaller degree is it influenced by warm or cold currents flowing into it". He further indicated that the wide seasonal variation in salinity characteristic of the Gulf is due to local conditions,..."the water freshening at the season of the spring freshet and then gradually salting again as this inrush of river water is incorporated by the mixings and churnings caused by the tides, winds, and waves". In this regard, it would appear that a great salinity influence on coastal waters would be exerted by the Penobscot Bay area.

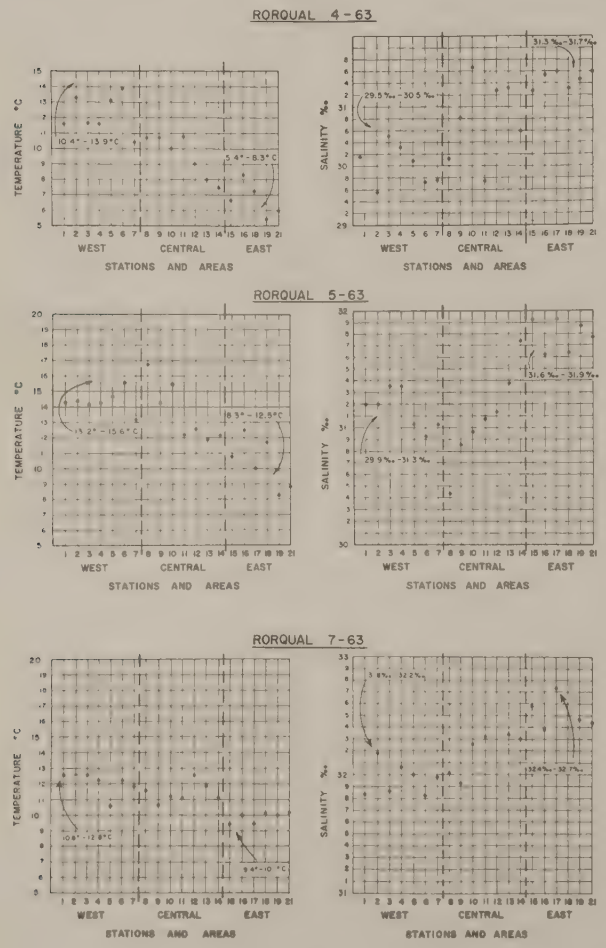

Fig. 7. Areal distribution of surface salinities and temperatures, *Rorqual* cruises 4, 5 and 7, 1963.

Surface temperatures and salinities plotted for spring, summer, and fall by areas (Fig. 7) suggest that the Penobscot Bay region represents a transition zone between surface waters of lower salinity and higher temperature ranges located in the western sector and higher salinity, cooler waters of the eastern area. Whether these environmental differences are the result of local conditions or advection cannot presently be determined, but will be subject to future investigation. In addition to hydrographic differences, faunal changes east and west of Penobscot Bay occur for: 1) mean length at age of immature herring, 2) erythrocyte antigen frequencies of two-year-old herring, 3) myxosporidian parasite infestation of young herring, 4) differential herring spawning as evidenced by length frequencies of larvae. The high zooplankton volumes, greater numbers of groups, and copepod species found in the western Gulf, when considered with the surface temperature and salinity differences, suggest that the Penobscot Bay region represents a faunistic boundary between eastern and western coastal biota.

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THE USE OF HARD PARTS OF FISHES FOR GROWTH DETERMINATION

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Background:

The science of oceanography presents a wide opportunity for original research in the general areas of biology, physics, and chemistry. One of the newer sciences resulting from man's increased interest in the oceans is Fishery Biology. Generally, Fishery Biology can be described as that segment of oceanographic research concerned with a number of varied problems including genetics, physiology, ecology, taxonomy, and population dynamics of fishes. Of primary interest in many government fishery research laboratories are the factors responsible for the large-scale periodic fluctuations in abundance of commercially important fishes. An important consideration of this problem is the knowledge of the growth pattern of the fishes investigated. This information is essential if the fishing industry is to be provided with sound biological manage-

ment practices which will allow the maximum sustained yield of the fishery in question. There remain virtually thousands of marine and also freshwater fishes which, as yet, are not the subject of intensive fisheries, however as the world demand for protein increases, so the ever present groups of "little known" fishes will be subject to increased fishing pressure.

Knowledge of the growth pattern of these "little known" fishes will aid in developing proper management policies for their future exploitations.

Suggested Approach:

Every state has a segment of the administrative body designed to manage the local fish and game. These agencies are known by various titles: State Division of Fish and Game, Department of Conservation, Fish and Game Commission, etc. The Federal Government also has a large number of fishery research laboratories located near fishing centers throughout the country. These laboratories are staffed by personnel of the Fish and Wildlife Service of the Interior Department. By contacting these agencies it will be possible to obtain information regarding the local species of fishes for which little or no growth information is available.

Examination of the hard parts of these fishes such as scales, opercules (gill covers), otoliths (sagitta bone found in skull), spines, and vertebrae will usually reveal a concentric pattern of alternating dark and light bands which in the temperate regions of the world represent the rapid spring-summer growth period (usually opaque area) and the sluggish growth or absence of growth characteristic of the winter-fall season (usually translucent). This growth pattern is similar to the an-

nual rings found in the cross section of most any tree in the temperate regions of the world. The opaque and translucent areas represent one annulus or year of growth. By counting the number of annuli it is possible to estimate the age of the fish under investigation.

A linear relationship usually exists between the seasonal size increase of the bony structure examined and the total fish length. The comparison of fish length to weight will provide information which can be used to determine the optimum cropping size with the addition of other data, including fecundity studies.

Descriptions of methods for securing and preparing the various hard parts of fishes and also procedures for data analysis are included in the list of general references.

If careful records are kept concerning fish length, weight, sex, and approximate age they could be incorporated into a formal report and forwarded to the editors of *Science World Magazine,* or scientific publications concerned with fishery research. (*See* Appendix in Rounsefell [3] for listing of fishery periodicals.) Accurate records of this sort would provide a significant contribution to fishery biology literature while also adding to man's understanding of his environment.

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Paracineta sp., an Epizoic Suctorian Found on Gulf of Maine Copepoda

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SYNOPSIS. An epizoic suctorian from Gulf of Maine coastal waters, designated as *Paracineta* sp., is described. Morphological measurements are given for 23 small, medium, and large specimens. Mean length was 200 μ and average cell body diameter 39 μ. Of 21 copepod species and 19 zooplankton groups examined, only copepods of the genus *Metridia* showed any *Paracineta* attached. Suctorian occurrence was, with a single exception, limited to adult copepods, with the larger females showing the heaviest incidence. Differences in areal occurrence were observed with greatest incidence of *Paracineta* on *M. lucens* in the eastern and central Gulf, and lowest numbers in the western area. This differential occurrence is accredited to an apparent cold water affinity of the suctorian. It is suggested that *Paracineta* could be carried into the Gulf during periodic intrusions of cool Nova Scotian water, reaching the western area in the southwesterly flowing Gulf of Maine eddy system. No significant differences in vertical distribution were found in *Paracineta* incidence on *Metridia* among the depths sampled (0, 10, 30, and 60 m). No harmful effect of *Paracineta* on *Metridia* was evident.

DURING examination of Gulf of Maine coastal zooplankton, large numbers of an epizoic marine suctorian belonging to the genus *Paracineta* were observed attached to the copepods *Metridia lucens* Boeck and *Metridia longa* (Lubbock). Previous observations of suctorians epizoic on several genera of marine copepods have been reported from widely scattered areas (Table 1). No previous record of *Paracineta* on the genus *Metridia* has been reported from the western Atlantic. This report describes the suctorian and presents observations on host specificity among zooplankters, host condition, distribution, and seasonal occurrence.

Paracineta sp. (Suctoria, Podophryidae) (Fig. 1)

The diagnosis given here is based on morphological measurements of 23 small, medium, and large specimens removed from five female *M. lucens* (Table 2). All measurements were made of specimens fixed in 10% formalin and stored in 70% methyl alcohol.

Diagnostic characters of the genus *Paracineta* have

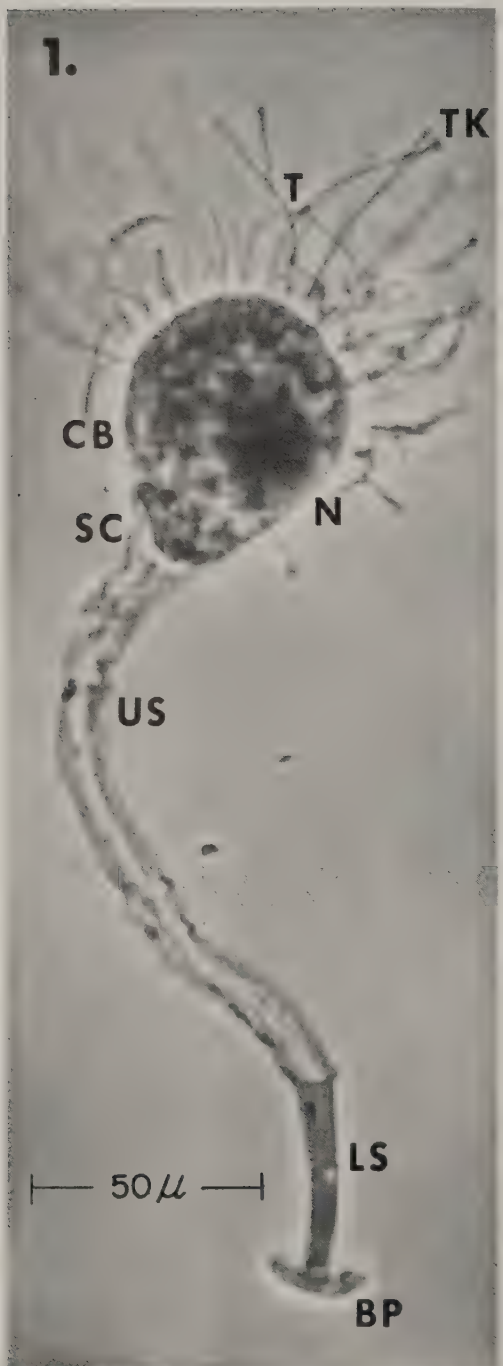


Fig. 1. The suctorian epizoic *Paracineta* sp. (483× phase contrast) BP, Basal plate; LS, Lower-stalk; US, Upper-stalk; SC, Supporting cup; CB, Cell body; N, Nucleus; T, Tentacles; TK, Tentacle knobs.

Fig. 2. Incidence of *Paracineta* attachment on *Metridia lucens*; A) Slight-incidence, B) Moderate-incidence, and C) Heavy-incidence.

TABLE 1. *Previous observations of suctorian epizoics on marine copepods.*

Author	Suctorian species	Copepod host	Geographic location
Canu(2)	Acinetidae	*Tachidius discipes* *T. littoralis* *Idya furcata*	Vicinity of Boulannais, France
Claus(4)	*Ophryodendron trinacrion*	*Tisbe furcata*	Vicinity of Messina, Italy
Jepps(7)	*Ephelota* sp.	*Calanus finmarchicus*	Clyde Sea area
Lebour(8)	*Ephelota crustaceorum*	"on the legs of a copepod"	Vicinity of Plymouth, England
Rose(11)	*Ephelota gemmipara* Unknown	*Calanus finmarchicus* *Candacia armata*	Vicinity of Roscoff, France Aermelkanal, Germany
Rose(12)	*Ephelota* sp.	*Pontella mediterranea*	Bay of Algiers
Rose(13)	Unknown	*Disseta palumbo*	Mediterranean
Schröder(14)	*Tokophyra interrupta* *Tokophyra campanula*	*Euchaeta* and *Metridia* sp.	South Atlantic
Schröder(15)	*Tokophyra steueri*	*Euchaeta hebes*	Adriatic
Schulz(16)	*Acineta tuberosa*	"on the abdomen of copepods"	Brackish water of the Bottsandgebeit, Germany
Sewell(17)	*Acineta euchaetae* *Paracineta gaetani* *Hallezia scottocalani*	*Euchaeta wolfendeni* *E. marina* *Gaetanus antarcticus* *G. curvicornis* *Scottocalanus dauglishi*	Arabian Sea
Steuer(18)	*Paracineta pleuromammae*	*Pleuromamma xiphias* *P. abdominalis*	Benguela current
Steuer(19)	*Ephelota gemmipara* *Paracineta pleuromammae*	*Pleuromamma borealis* *P. gracilis* *P. gracilis* *P. borealis*	Benguela current

been given by Collin(5) and include the following: monaxial symmetry, with tentacles radiating from the body and never fasiculated; style long and thin with striated bundles reduced or absent; and reproduction by exogenous budding.

Diagnosis. Total length, measured from the upper pole of the cell body to the margin of the basal plate, ranged from 131 to 262 μ with a mean of 200 μ. The cell body varied from spheroid to pear shape ranging in diameter from 23 to 66 μ with a mean of 39 μ. A single rounded nucleus, with a mean diameter of 11 μ was present in each of the 23 specimens. In a medium of lactic acid and methyl blue, coarse granules and refractile particles could be distinguished in the protoplasm. A spherical contractile vacuole measuring 7 μ in diameter and located at the cell body periphery was observed in one specimen. The cell body is supported by an elongated flexible upper-stalk, which thickens into a supporting cup at the distal end, and a shorter rigid lower-stalk modified into a basal plate at the proximal end, which adheres to the host. The lower-stalk is approximately one-third the length of the upper-stalk. In all specimens examined, the greatest number of tentacles were located on the upper half of the cell body. When extended they were equal or greater in length than the cell body diameter (Fig. 1).

TABLE 2. *Morphological measurements of* Paracineta *sp.*

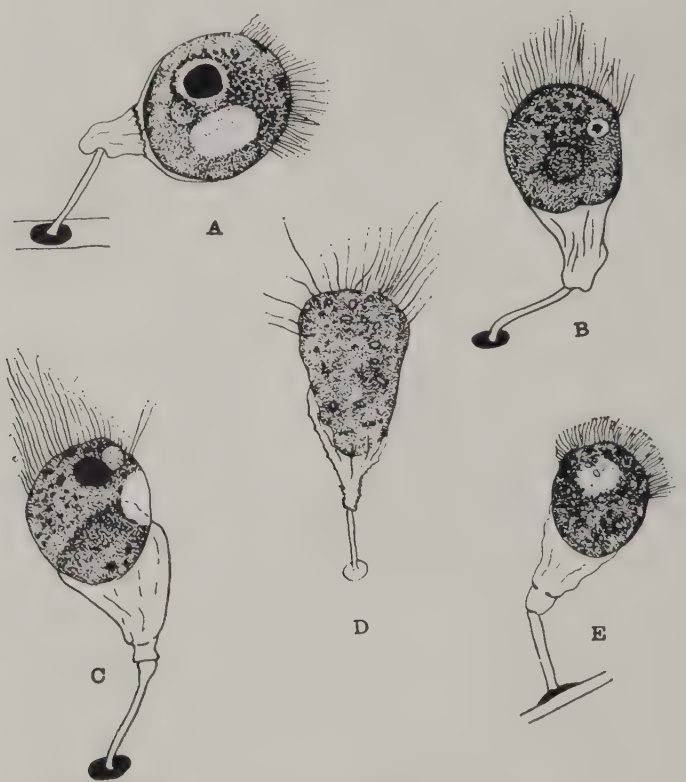
	Range (μ)	Mean (μ)
Total length	131–262	200
Upper-stalk length	47–155	106
Broad aspect of supporting cup	9– 28	16
Lower-stalk length	23– 52	38
Lower-stalk diameter	5– 9	6
Basal plate diameter	9– 23	15
Cell body diameter	23– 66	39
Nucleus diameter	7– 14	11
Vacuole diameter	7	

Remarks. The present species resembles *Paracineta gaetani* Sewell (Fig. 3A) and *Paracineta pleuromammae* Steuer (Fig. 3B). In *P. gaetani* the flexible upper-stalk is thicker and shorter, with a mean length $\leqslant 38$ μ in *P. gaetani* Sewell(17), as compared to 106 μ in *Paracineta* sp. The upper-stalk in *P. pleuromammae* is greatly thickened, providing a cup-like support which covers nearly one-half of the cell body. In *Paracineta* sp. the supporting cup is greatly reduced covering approximately one-fourth of the cell body surface. Structure of the tentacles is wider than in *Paracineta* sp., with the distal knob less distinctly formed(19). Information regarding specimen preservation of *P. gaetani* and *P. pleuromammae* was not available in the literature. However, the ratios of various body parts, particularly the upper and lower stalks, and the basic structure of the cell body supporting cup would not be expected to undergo radical change with preservation.

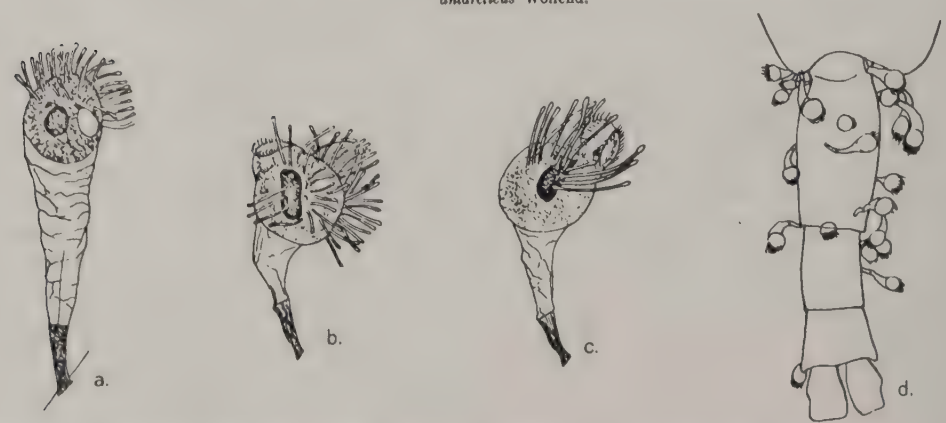
METHODS

Examination for the presence of *Paracineta* was made on copepod species and other zooplankton groups from 120 samples collected from Gulf of Maine coastal waters during spring, summer, fall (1963), and winter (1964). Station locations, dates of sampling, and locations of *Paracineta* occurrence are given in Fig. 4. Two types of zooplankton sampling de-

vices were used: a high-speed Gulf III sampler, and Clarke-Bumpus (CB) closing-nets. The Gulf III sampler was towed at approximately six knots for 30 min in a step-oblique manner, with 10 min each at the surface, 10, and 20 m. This gear was used on the spring and summer cruises of the *R. V. Rorqual*. Clarke-Bumpus samplers were used on the surveys conducted during the fall and winter. When depth and bottom topography permitted, simultaneous 15-min hauls at 0, 10, 30, and 60 m were made. All tows were taken during daylight hours. Numbers of zooplankters per 100 m^3 of water strained were determined for samples collected during *Rorqual* spring and summer cruises. Numbers per 10 m^3 of water strained were calculated for collections made during *Rorqual* fall and winter cruises.



TEXT-FIG. 8.—*Paracineta gætani* sp. nov. A–E, Different individuals from the same host, *Gætanus antarcticus* Wolfend.



Textfig. 188 a—d. *Paracineta pleuromammae* STEUER 1928. b, c Knospung. d an *P. gracilis* (CLS.), ♀ von Station 85. V. 700 m.

Fig. 3. The suctorians, A) *Paracineta gaetani*, from Sewell, B) *Paracineta pleuromammae*, from Steuer.

TABLE 3. *Copepod species and major zooplankton groups examined for* Paracineta *incidence.*

Copepod species	Major zooplankton groups
Acartia clausi Giesbrecht	Amphipoda
Acartia longiremis (Lilljeborg)	Annelida
Calanus finmarchicus (Gunnerus)	Brachyura (larvae)
Calanus hyperboreus Kroyer	Chaetognatha
Candacia armata (Boeck)	Cirripedia (larvae)
Centropages hamatus (Lilljeborg)	Cladocera
Centropages typicus Kroyer	Copepoda nauplii
Euchaeta norvegica Boeck	Crustacean eggs
Eurytemora herdmani Thompson and Scott	Cumacea
Metridia longa (Lubbock)*	Cyclopoid copepoda
Metridia lucens Boeck*	Decapoda (larvae)
Microstella norvegica (Boeck)	Euphausiacea
Oithona plumifera Baird	Fish eggs
Oithona similis Claus	Harpacticoid copepoda
Oithona spinirostris Claus	Medusae
Paracalanus parvus (Claus)	Pelecypoda
Pleuromamma robusta (Dahl)	Pteropoda
Pseudocalanus minutus (Kroyer)	Siphonophora
Scolecithricella minor (Brady)	Tunicata
Temora longicornis (Muller)	
Tortanus discaudatus (Thompson and Scott)	

* *Paracineta* present.

RESULTS AND DISCUSSION

Zooplankton Specificity

Of the 21 copepod species and 19 other zooplankton groups found in our samples, only *M. lucens* and *M. longa* showed any evidence of *Paracineta* attachment, indicating a high degree of host specificity among Gulf of Maine coastal zooplankters. Copepod species and major zooplankton groups examined for *Paracineta* incidence are listed in Table 3. *Paracineta* were found only during fall and winter (Table 4).

Three categories of *Paracineta* incidence on *Metridia*, based on estimated numbers of suctorians present per copepod, were recognized: slight (1-50), moderate (ca. 50-100), and heavy (ca. 100-250). In cases of slight incidence, suctorians were found on the furca, urosomal segments, and occasionally on the posterior margin of the fourth metasomal segment (Fig. 2A). The attachment area extended anteriorly from the caudal furca to the second metasomal segment region in cases of moderate incidence (Fig. 2B), and over the entire dorsal surface, sides of the metasome, and around the furca in cases of heavy incidence (Fig. 2C).

Examination for possible copepod size-selectivity by *Paracineta* was made by obtaining length-frequency measurements (from anterior cephalosome to caudal furca posterior margin) of all affected and non-affected *M. lucens* taken from the winter sample with highest suctorian incidence. Lengths ranged from 1.09 mm to 3.22 mm; with males ranging from 1.85 mm to 2.13 mm, and females from 2.54 mm to 3.22 mm. Immature forms measured less than 1.85 mm, with the exception of several stage V *M. lucens* less than 2.54 mm, which could be identified as developing females. *Paracineta* were found only on adult *M. lucens*. All other *M. lucens* and *M. longa* in our samples were examined, with no evidence of *Paracineta* incidence on immature copepods except for a single developing male measuring 1.76 mm in length. General absence of affected immature *M. lucens* implies that either *Paracineta* is lost through molting, or that the suctorian favors adult forms as a substrate.

Suctorian-incidence by sex among adult *M. lucens* was determined for all samples. A differential occurrence was found between males and females, with 96% of males showing slight incidence and 4% with moderate incidence. Among females 75% showed slight, 15% moderate, and 10% heavy incidence of *Paracineta*. Of 12 female *M. longa* affected, 11 showed slight and one moderate incidence. Affected females outnumbered males in our samples at a 3:1 ratio. Dominant metridian forms in all of our samples were adult females and immature specimens. The higher suctorian incidence among females is accredited to their great numbers and large size, which would appear to favor them over the smaller males as a suitable substrate.

Distribution

Numbers of affected and non-affected *M. lucens* found during winter were compared by coastal area—western, central, and eastern (Table 5). A X^2 value of 12.23 (2 df, $P<.01$), indicated that differences found among areas were significant, with greatest occurrence in the eastern (17%) and central (16%) areas, and lowest in the western region (12%). The only other *Paracineta* occurrence was at a single station (where 106 affected *M. lucens* occurred) located on the easternmost transect during fall (Fig. 4).

Salinity and temperature values were plotted with

TABLE 4. *Total numbers of affected and non-affected* M. lucens *and* M. longa *for each of the seasonal cruises.*

	Spring	Summer	Fall	Winter	
	M. lucens No./100m³	*M. lucens* No./100m³	*M. lucens* No./10m³	*M. lucens* No./10m³	*M. longa* No./10m³
Non-affected	5,592	12,344	13,159	2,887	140
Affected	—	—	106	487	12

TABLE 5. *Numbers of affected and non-affected* Metridia lucens *by coastal area, winter, 1964.*

Area	*M. lucens* Affected No.'s/10m³	Non-affected No.'s/10m³	Total No.'s/10m³	Percent affected
East	146	711	857	17.04
Central	146	779	925	15.78
West	195	1397	1592	12.25

total numbers of affected and non-affected *M. lucens* to determine the possible relation of these variables on *Paracineta* distribution (Figs. 5A and B). Greatest occurrence of suctorian concentration paralleled the abundance of *M. lucens* in high salinity water (>32.50 ‰). However, incidence of affected *M. lucens* was reduced from 51-100/10 m³ to less than 25/10 m³ in water warmer than 4.1°C (Fig. 5A). Immigrant cold-water zooplankters, found in periodic intrusions of Nova Scotia water, have been reported from the eastern Gulf of Maine(1). It is possible that areal differences in suctorian incidence could be related to periodic cold-water intrusions, with fewer numbers reaching the western Gulf during their planktonic free-living embryonic period in the southwesterly flowing Gulf of Maine eddy system. Absence of *Paracineta* during warmer months (May to July), low numbers found in fall, and high numbers in winter suggest that this suctorian is associated with cool waters.

Metridia lucens is known to undertake day-night vertical migration with maximum numbers occurring in deep water during daylight hours, and at the surface at night(3,10). The incidence of affected and non-affected *M. lucens* between and among depths was compared for samples collected during winter (Table 6). No significant differences in X^2 values were found between depths. A X^2 value of 0.92 (3 df) demonstrated that no significant differences among depths

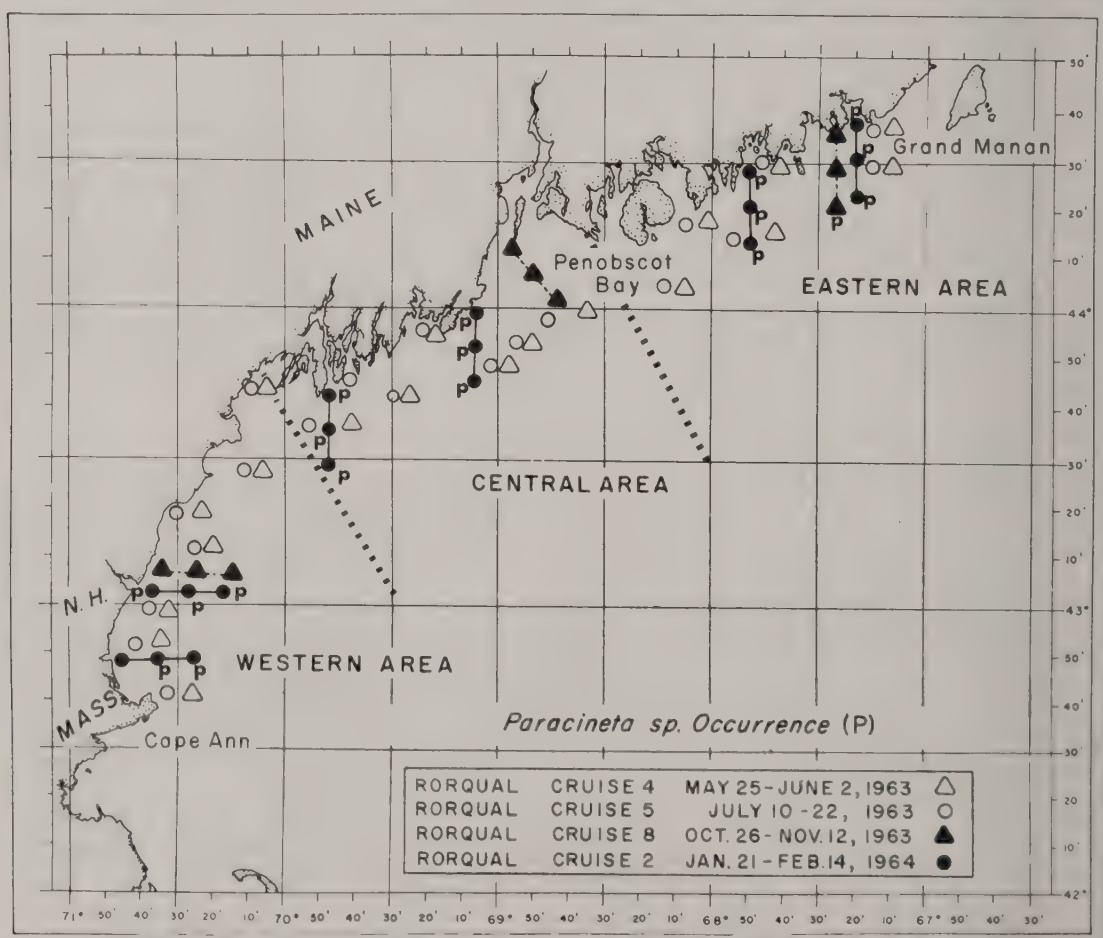


Fig. 4. Station locations and periods of zooplankton collections made during spring, summer, fall (1963), and winter (1964).

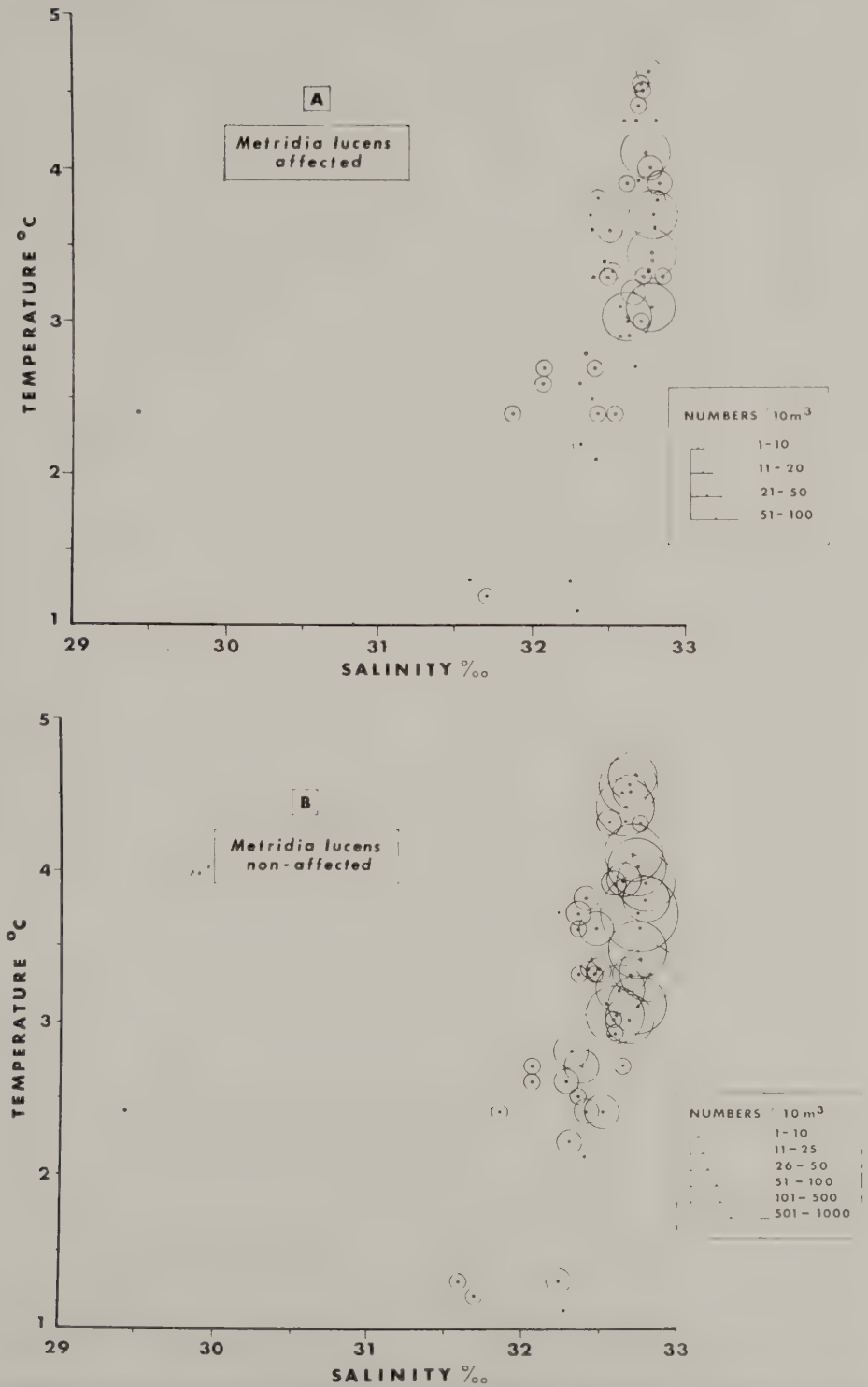


Fig. 5. Comparison of salinity, temperature, and total numbers of *Metridia lucens*; A. Affected *M. lucens*, B. Non-affected *M. lucens*. Circle diameter size represents number of *M. lucens* per $10m^3$ of water strained.

TABLE 6. *Numbers of affected and non-affected* Metridia lucens *by depth, winter, 1964.*

Depth (meters)	*M. lucens* Affected No.'s/10m³	*M. lucens* Non-affected No.'s/10m³	Total No.'s/10m³
0	11	74	85
10	56	332	388
30	188	1169	1357
60	232	1312	1544

occurred within the range sampled (0-60 m), suggesting that the 0-20 m oblique samples collected during *Rorqual* spring and summer cruises provided adequate collections for seasonal comparison of *Paracineta* incidence. No loss of attached *Paracineta* by abrasion or turbulence was observed in several samples available for examination, which were collected with the high speed Gulf III sampler during winter, 1964.

Condition of Host

Suctorian epizoons use the host species as a substrate, adhering by means of a cementing substance secreted by the free-living embryo on contact with the host(5). They are predaceous on smaller protozoans, generally using an array of tentacles located on the outer surface of the cell-body for capturing and ingesting prey(6). No penetration into the body tissues of either *M. lucens* or *M. longa* was observed. A distinct basal-plate attached to the outer cuticle of the copepod host was found supporting all of the suctorians (Fig. 1). No apparent harmful effect was evident on visual comparison of affected and non-affected *M. lucens* of the same sex and length. It was not feasible to assess host condition by morphometric methods, since greatest growth of most crustaceans is known to occur only during a brief period in the intermolt cycle (9). Affected *Metridia* specimens, with one exception, were adult forms. Laboratory observations of *Metridia* behavior, particularly swimming efficiency, would provide more definitive information regarding possible effects of *Paracineta* attachment.

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Reprinted from JOURNAL OF MAMMALOGY
Vol. 46, No. 3, 26 August 1965
pp. 500–501

STOMACH CONTENTS OF A DOLPHIN CAUGHT IN HAWAIIAN WATERS

Porpoises and dolphins are reported to feed on a wide variety of organisms (see Gunter, J. Mamm., 23: 267–276, 1942). The stomach contents of a dolphin, *Stenella attenuata* (Gray), caught in Hawaiian waters at 0620 hr on 18 August 1962, are herein reported. The specimen was a male: length of body, 170.5 cm from tip of snout to tail notch; weight, 89 lb; length of snout, 10.3 cm. The identification of the animal was based on a description by True (Bull. U. S. Fish Comm., 23, pt. 3: 809–816, 1903) of two specimens of *Prodelphinus attenuatus* (Gray) taken in Hawaiian waters in 1901. We were informed by Dr. K. S. Norris (pers. comm.) that the proper designation for this species is *Stenella attenuata* (Gray). The skull will be sent to the U. S. National Museum for final disposition.

The specimen was taken approximately 3 miles off the western shore of Oahu in waters 180 fathoms in depth. It was alive when landed but died a few minutes later. The relatively undigested condition of the organisms found in its stomach suggests that it had fed during the early hours of the morning and had become entangled in the net shortly before it was hauled.

Table 1 lists the number, displacement volume, per cent volume and size of the organisms identified from its stomach contents. Since some of the stomach walls of the fishes found in the dolphin were partly digested, it is likely that the nemertean worms and the crab larvae came from the fishes rather than being directly consumed by the dolphin. Squids were the most abundant food item, making up 86% of the total volume. This finding provides further evidence that squids are a principal food for the larger marine predators. King and Ikehara (Bull. U. S. Fish and Wildlife Service, 108: 61–85, 1956) reported that squids constitute approximately 30% of the food of yellowfin tuna (*Thunnus albacares*) and bigeye tuna (*T. obesus*). Among the fishes, myctophids (family Myctophidae) were the most abundant, comprising 6% of the total volume of food. Because the dolphin was captured at sunrise, it may have preyed on the myctophids and the other fishes and squids in the surface waters prior to sunrise and, thus, prior to the downward movement of these forage organisms. Very little is known about dolphin feeding habits; the possibility that they dive into deep waters to feed should not be discounted. Myctophids are apparently an important item in the diet of porpoises and dolphins. Wilke and Nicholson (J. Mamm., 39:

TABLE 1.—*Stomach contents of a dolphin,* Stenella attenuata *(Gray), caught in Hawaiian waters on 18 August 1962*

Item	Number	Displacement volume (cc)	% volume	Size range (cm)
Squids				
Abralia astrosticta	258	656	51.5	2.3–3.7 (mantle length)
Ommastrephes hawaiiensis	3	435	34.1	11–19 (mantle length)
squid beaks	2			
Fishes				
Paralepididae	7	20	1.6	13–15
Alepisauridae	3	28	2.2	15 (estimated avg)
Gempylidae	3	10	0.8	12 (estimated avg)
Bramidae	8	55	4.3	5–10
Myctophidae	16	70	5.5	6–10
Others				
nemertean worms	4			
crab larvae	3			

441–443, 1958) reported that this group comprised 70% (by volume) of the total food found in the stomachs of 161 True porpoises and 7 Dall porpoises captured near Japan.

Although the dolphin was captured only 3 miles from shore, all organisms found in its stomach were pelagic forms; no littoral or neritic form was present.

With the exception of the myctophids, none of the other fishes has been reported to be common in Hawaiian waters. Unless the presence of these fishes in the stomach of this dolphin was unusual, the results emphasize the inadequacy of our methods of assessing the presence and abundance of small organisms in Hawaiian waters.—Richard S. Shomura and Thomas S. Hida, *U. S. Fish and Wildlife Service, Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii.* *Accepted 5 April 1965.*

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Effects of Environment on Several Diseases of Herring from the Western North Atlantic.

BY CARL J. SINDERMANN

Reprinted from

International Commission for the Northwest Atlantic Fisheries
Special Publication Number 6, 1965.

Reprinted from
International Commission for the Northwest Atlantic Fisheries
Special Publication Number 6, 1965.

E-5

EFFECTS OF ENVIRONMENT ON SEVERAL DISEASES OF HERRING FROM THE WESTERN NORTH ATLANTIC

By

Carl J. Sindermann[1]

ABSTRACT

Several diseases and parasites of herring (*Clupea harengus harengus*) from the western North Atlantic have been investigated during the past eight years. Two important parasites of immature herring, a myxosporidian (*Kudoa clupeidae*) and a larval trematode (*Cryptocotyle lingua*) were found to be distributed discontinuously in the Gulf of Maine, occurring with greatest abundance in the western coastal area. The occurrence of both parasites seems directly related to summer sea water temperature. Study of a systemic disease of herring caused by the fungus *Ichthyosporidium hoferi* has disclosed apparent periodicity of epizootics and has provided experimental evidence for the importance of high spore concentrations in the environment to abundance and severity of the disease in herring. Since parasites and their abundance are often characteristic of particular age groups of geographic areas, information about herring stocks and their movements has been obtained.

INTRODUCTION

Among the biological features of the environment that affect the abundance of marine species, disease is of great significance. This can be best demonstrated in inshore sedentary species, but applies to pelagic or demersal species as well. Few pelagic species have been adequately examined for diseases, but during the past decade the U.S. Bureau of Commercial Fisheries Biological Laboratory, Boothbay Harbor, Maine, USA, has carried on a continuing study of diseases and parasites of Atlantic herring, *Clupea harengus harengus*. Attention was first directed to disease in this species because of recurring epizootics of a systemic fungus pathogen (*Ichthyosporidium hoferi*), the most recent of which occurred in the Gulf of Saint Lawrence in 1954-55 and the Gulf of Maine in 1947. The fungus disease has been studied continuously at the Boothbay Harbor Laboratory since 1947 and other diseases and parasites of herring have also been examined.

Many extrinsic and intrinsic factors combine to determine the incidence, distribution, and effect of disease on herring populations. Extrinsic factors include such environmental influences as temperature, salinity, availability of vectors or alternate hosts, and infection pressure (the relative numbers of infective organisms present in the environment at a given time). Intrinsic factors are those which determine susceptibility to disease, including individual and population levels of natural or acquired resistance, and nutritional state of the fish.

The isolation of specific factors in one or the other category is difficult, since many have aspects that fall in both -- for example, immune responses in poikilothermic animals are intrinsic, but are clearly influenced by environmental temperature. Despite some overlap, an attempt has been made to confine this paper to examples of extrinsic or environmental factors that affect certain diseases and parasites of herring in the western North Atlantic. Only three diseases, "pigment spot" caused by metacercariae of the trematode *Cryptocotyle lingua*, myxosporidian disease caused by *Kudoa clupeidae*, and fungus disease caused by *Ichthyosporidium hoferi*, will be considered here, and of these only those aspects pertinent to environmental influences will be included.

PIGMENT SPOT DISEASE

Ecological information is available for the larval trematode *Cryptocotyle lingua*, an important parasite of western North Atlantic herring. The worm occurs as a metacercaria in the skin and flesh. It's life cycle in the Gulf of Maine (Fig. 1) includes the common periwinkle *Littorina littorea* as a first intermediate host and the gull *Larus argentatus* as the definitive host. Herring are

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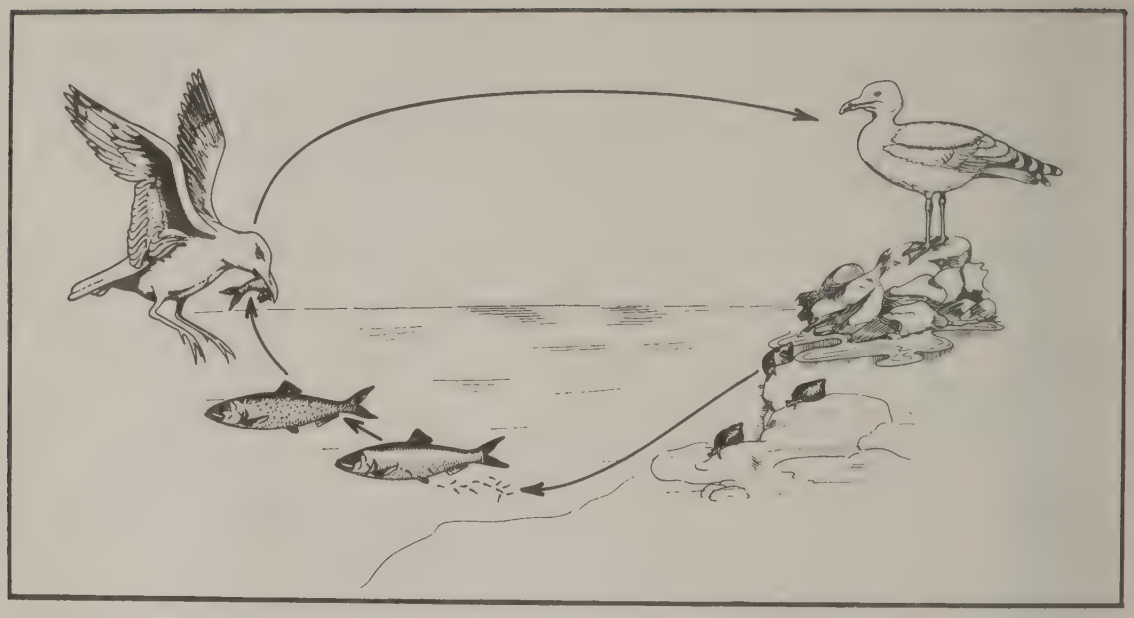


Fig. 1. Life cycle of *Cryptocotyle lingua* in northern New England.

important second intermediate hosts in this region of the western Atlantic. Examination of immature herring from coastal waters of the Gulf of Maine in 1961, 1962 and 1963 disclosed marked geographic variation in intensity of parasitization by *Cryptocotyle* metacercariae. Degree of parasitization was determined according to the following criteria: uninfected; lightly infected (1-5 metacercariae); moderately infected (6-50 metacercariae); heavily infected (over 50 metacercariae). A parasite concentration index (Sindermann 1953) was obtained for each sample by ranking each individual according to the following scale: uninfected (0), lightly infected (1), moderately infected (2), and heavily infected (3). Summation of ranks for each sample of 50 fish provided a concentration index for the sample. Numbers of samples examined were 20 in 1961, 26 in 1962 and 30 in 1963. The northern New England coast was divided into major areas with the following boundaries: (A) Isles of Shoals eastward to Cape Small; (B) Cape Small to Matinicus Island, (C) Matinicus Island to Mount Desert Island; (D) Mount Desert Island to West Quoddy Head; (E) West Quoddy Head to the Saint John estuary. Concentration indices for all samples in each area were averaged in each year to obtain a single index for the area and year (Fig. 2). Parasite concentration indices decreased sharply from west to east in each year.

Since parasitization of herring depends on availability of infective cercariae, a study was made in the summer and early autumn of 1963 of incidences of *Cryptocotyle* larvae in *Littorina*, the first intermediate host. Samples of 50 snails each were collected in the high tide zone from as many locations as possible. Infection was determined by crushing the snail and examining the digestive gland. Results grouped by major coastal areas are presented in Fig. 3. Wide variations in incidences within areas were noted, but no major variations on a coastwide basis were found. This was quite different from the geographic change in abundance of metacercariae in herring just mentioned and suggested that other environmental factors were important for completion of the parasite life cycle. Earlier studies (Sindermann and Rosenfield 1954*b*; Sindermann and Farrin 1962) demonstrated a direct relationship between temperature and cercarial emergence. Emergence declined with lowered sea water temperatures and ceased when temperatures fell below 10°C. Examination of coastal temperatures in July, 1963 (Fig. 4) suggests that the northern New England coast may be a critical zone for the parasite. Easternmost areas, with colder summer sea temperatures, were characterized by much lower parasite indices in herring. Factors other than temperature may be operative, since earlier experimental studies demonstrated that cercarial emergence was also inhibited by salinities below 18 °/oo (Sindermann and Farrin, *op. cit.*). However, no east-west change in salinity was observed in hydrographic data for 1963 that would be great enough to account

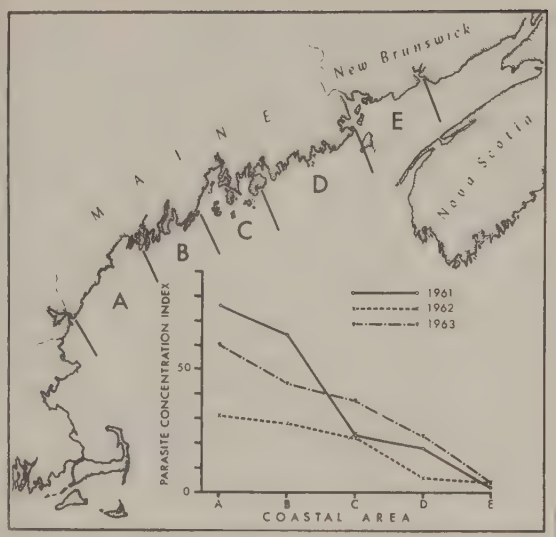
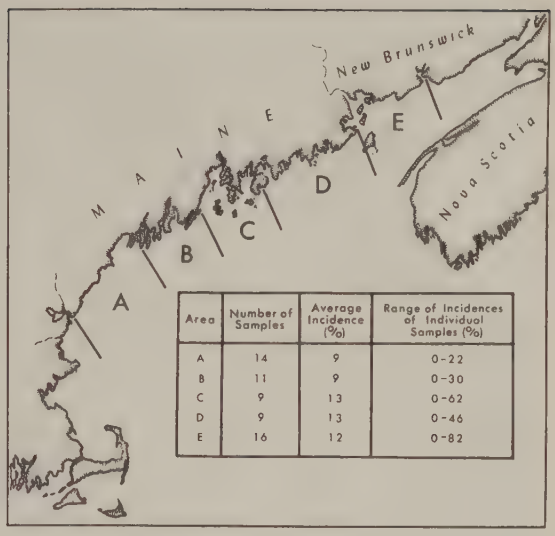


Fig. 2. Coastal sampling areas and concentration indices of *Cryptocotyle lingua* metacercariae in immature herring 1961-63.



Area	Number of Samples	Average Incidence (%)	Range of Incidences of Individual Samples (%)
A	14	9	0-22
B	11	9	0-30
C	9	13	0-62
D	9	13	0-46
E	16	12	0-82

Fig. 3. Incidences of *Cryptocotyle* larvae in *Littorina littorea* from the high tide zone along the northern New England coast, 1963.

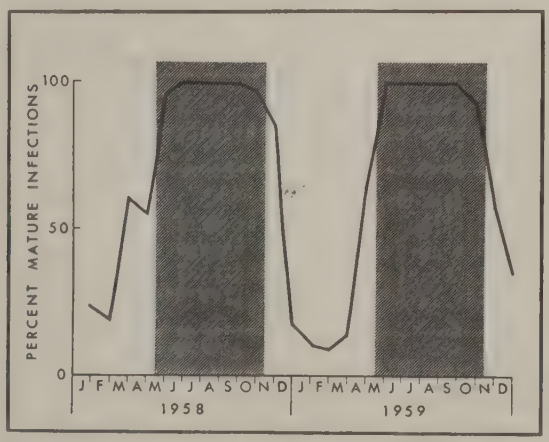


Fig. 4. Periods of the year when immature herring are most abundant in inshore waters (shaded zones) and average monthly maturity of snail infections (line graph). Mature infections are diagnosed by findings of fully-formed active cercariae in crushed snails.

for observed geographic changes in parasite incidences. Based on experimental findings, however, it would be possible for local changes in salinity to enhance or reduce effects of temperature on cercarial emergence.

The evidence suggests a relationship between environmental temperature in summer and degree of parasitization of herring by *Cryptocotyle*. There are of course still many questions to be answered. No information is available on possible geographic variations in degree of parasitization of the definitive host (the gull). Also, local variations in temperatures occur that could produce local anomalies in parasite abundance. For example 1963 hydrographic stations in the upper Penobscot Bay have disclosed July temperatures above 15°C, even though the general coastal area is described as a 10° to 15°C zone.

Comparisons of herring movements and availability of infective cercariae are striking. Immature fish are most abundant in inshore waters from May to November. This is the period when most snail infections are mature and producing cercariae, and maximum opportunity for parasite transfer exists. Results of a two-year study on one island off the central Maine coast are presented in Fig. 5. When cercariae are present in greatest numbers in inshore waters the susceptible second intermediate hosts are also present in abundance.

Fig. 5. Average distribution of summer sea water temperatures along the northern New England coast in 1963.

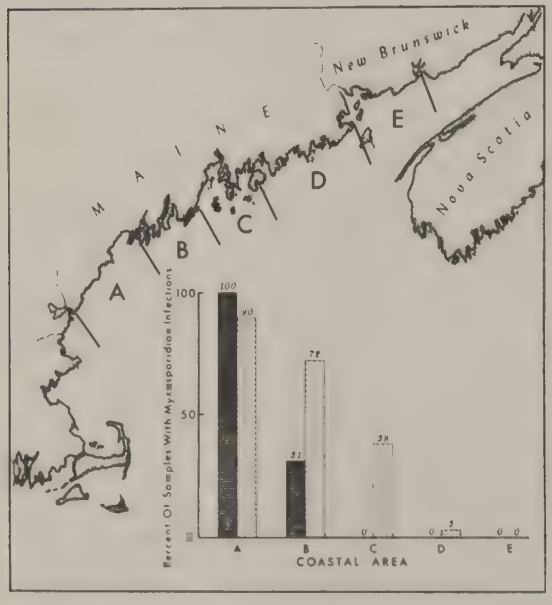


Fig. 6. Percent of samples of one-year-old (horizontal bar) and two-year-old (stippled bar) herring in which myxosporidia (*Kudoa clupeidae*) were present during the period 1955-63. Each sample consisted of 50 fish, and total samples of one-year-old fish were 112, and of two-year-old fish 242. Equal numbers of samples were not obtained in each year or for each area.

MYXOSPORIDIAN DISEASE

Another important parasite of western North Atlantic herring is the myxosporidian *Kudoa clupeidae*. This protozoan occurs in intramuscular cysts in immature herring. Infections are acquired in the early months of life and have been shown to persist in aquarium-held herring for two years, but were rarely found in adult fish (Sindermann and Rosenfield, 1954*a*; Sindermann, 1961). The geographic distribution of the parasite in Gulf of Maine herring has been studied since 1955. Infected fish were common along the western Maine coast, but were almost non-existent on the eastern Maine coast. Average incidences in the major coastal areas already described are presented in Fig. 6. Infections have not been found in one-year-old fish east of Matinicus Island. Infected two-year-old fish, with a single exception (one fish in a sample from Grand Manan Island in 1963) have not been found east of Mount Desert Island. The fect that infections were carried annually as far east as Mount Desert Island by eastward movement of infected two-year-old fish, while the disease organism did not occur east of Matinicus Island in one-year-old fish, indicates that some limiting influence on the diseast is operative. While other environmental factors may be important in determining the discontinuous distribution of *Kudoa*, temperature may exert a critical influence. Decreasing summer sea water temperatures from west to east along the coast (Fig. 4) correlate positively with parasite incidences, with Matinicus Island the general eastern limit of temperatures in excess of 15°C and the eastern boundary of infections in one-year-old fish.

Another indication of possible influence of temperature on the distribution of *Kudoa* is seen in the larger picture of its occurrence in herring of the western North Atlantic. Herring occur from Virginia northward to Labrador, with centers of abundance in the Gulf of Maine and the Gulf of Saint Lawrence. Although sampling has been concentrated in the Gulf of Maine, herring from the Rhode Island and New Jersey coasts, the Nova Scotia coast and the Gulf of Saint Lawrence have been examined since 1955. Infections were common in herring from Rhode Island and New Jersey, were absent on the Nova Scotia coast, but reappeared in the southern Gulf of Saint Lawrence where, because of shallow water, summer temperatures often reach 20°C. The parasite occurred in waters that characteristically exceed 15°C in summer and did not occur in waters with lower summer maximum temperatures (Fig. 7).

It is possible, of course, that factors other than environmental temperature may be important in determining the geographic distribution of *Kudoa clupeidae* in herring, or that temperature may act indirectly by influencing the distribution

Fig. 7. Coastal areas of the western North Atlantic (heavy shading) where summer sea water temperatures usually exceed 15°C and where *Kudoa clupeidae* occurs in immature herring.

of transfer or other hosts. The Myxosporidia are usually considered one-host parasites, but the possibility of an invertebrate intermediate host needs further exploration. If another marine species plays a role in determining abundance or distribution of *Kudoa* in herring, temperature may operate indirectly.

FUNGUS DISEASE

Another disease of Atlantic herring with interesting environmental relationships is that caused by a systemic fungus pathogen *Ichthyosporidium hoferi*. At least six epizootics of this disease have occurred in herring during the past 70 years, resulting in widespread mortalities and affecting abundance of the species in the western North Atlantic (Sindermann, 1963). Individual variations in susceptibility to the pathogen have been demonstrated (Sindermann, 1958) and an explanation of changes in disease abundance based on intrinsic factors such as changes in population susceptibility and extrinsic factors such as infection pressure has been proposed.

Infection pressure appears to be an ecological factor of significance in determining outbreaks of *Ichthyosporidium*. Transmission from fish to fish is effected by heavy-walled spores which have been found to survive in sea water cultures for over six months with no loss of viability. Spores have been demonstrated in inshore bottom sediments during an epizootic. Since during an outbreak peak an average of one-fourth of the population is infected, and since most infected fish die either from acute or chronic infections, the spore load in mortality areas can be very high.

Knowledge about the effects of increasing infection pressure on occurrence of the fungus disease in susceptible hosts has been obtained by experimental exposures and experimental epizootics created in aquarium populations of immature herring. Massive and repeated exposures were necessary to achieve infection in two-year-old fish (Table 1). Beyond a critical dosage level, acute as well as subacute or chronic infections resulted. With experimental demonstration of the effect of increasing spore dosage or infection pressure on prevalence and severity of the disease, a large scale experimental epizootic was created in a laboratory population of 2,000 one-year-old herring. Spore dosage of 2×10^5 spores on each of four consecutive days resulted in infection of 23% of the population--8% acute and 15% subacute. The disease was terminal in all acute cases within 30 days. Chronic or subacute infections resulted in death of all but very light cases within six months. As with most aquarium studies of this kind, occasional deaths due to causes other than fungus disease occurred in experimental and control groups during the 18 month observation period, but these were infrequent enough so that they would not materially alter the findings. At the termination of the experiment (18 months after initial exposure) all surviving individuals were examined; only three lightly infected fish were found.

Experimental results agree with findings during the last outbreak in Gulf of Saint Lawrence herring (Sindermann, 1958). Twenty-seven percent of all fish sampled in that Gulf during the epizootic peak were infected, the ratio of acute to subacute being approximately one to two. Disease incidence was very low when spawning fish first appeared on the coast in late April, but mortalities due to acute infections began about one month after inshore migration. Deaths continued at a low level throughout the summer, due to subacute infections. A related observation of the effect of infection pressure concerned the alewife, *Alosa pseudoharengus*. This species has been reported, principally on the basis of histological evidence, to be less susceptible to *Ichthyosporidium*, by Sindermann and Scattergood (1954). During the recent epizootic in herring, alewives present in inshore waters also became infected, in sufficient numbers so that mortalities were observed and reported.

TABLE 1. SPORE DOSAGE AND EXPERIMENTAL INFECTION RATE IN TWO-YEAR-OLD HERRING. (Experimental groups of 50 fish each, from a laboratory population previously found to be free of fungus disease, were maintained in 250 gallon sea water tanks. Spores were obtained from naturally infected fish and tested for viability by culturing in Sabouraud-serum agar. Spore suspensions were added to food just before the fish were fed. The experiment was terminated at 90 days, and surviving fish examined for gross or histological evidence of disease).

Exposure and Dosage Schedule	Observations
2×10^5 spores in single exposure	No gross or histological evidence of disease after 90 days.
2×10^5 spores on each of 3 consecutive days	After 90 days, 4 of 50 fish had subacute or chronic infections; spores few and encapsulated; other fish uninfected.
2×10^5 spores on each of 5 consecutive days	After 20 days, 1 fish dead with massive acute infection; extensive tissue necrosis; little host response. After 90 days, 10 of remaining 49 fish exhibited subacute or chronic infections of varying severity; 39 fish uninfected.
2×10^5 spores on each of 7 consecutive days	After 15 to 30 days, 5 fish dead with massive acute infections. After 90 days, 12 with subacute infections of varying severity; 33 fish uninfected.
Control (no spore exposure)	No gross or histological evidence of disease.

DISCUSSION AND SUMMARY

The distribution and abundance of many parasites of herring vary geographically to such an extent that several have been used as "natural tags" in migration and population studies. Incidences of encysted larval cestodes (Trypanorhyncha) and nematodes (Anisakinae) have been examined over much of the range of herring in the western North Atlantic (Sindermann, 1961), and have been found during eight years of sampling to occur with characteristic frequencies in different geographic areas. Undoubtedly the presence and abundance of infected first intermediate and definitive hosts for these worms plays a role in determining parasitization of herring, although environmental variables might also be of importance.

Age of the herring is related to the kinds and numbers of parasites found. Certain parasites are characteristic of only very young fish, others only of older fish, while still others occur in herring of all ages. Adult cestodes (Pseudophyllidea) and a sporozoan (*Plistophora* sp.) occur only in herring younger than six months; the myxosporidian *Kudoa clupeidae* occurs only in immature

fish; larval cestodes (*Trypanorhyncha*) occur only in fish older than one year; while the fungus *Ichthyosporidium hoferi* may occur in fish of any age. Diet, proximity to other hosts in the life cycle, segregation by size in schooling, and increasing immunity with age may all be of importance to the changing spectrum of disease with age. Research in the USSR that can best be described as ecological parasitology of fishes has been admirably summarized by Dogiel *et al.* (1958). Changes in parasite fauna of marine fishes with age and geography have been documented for a number of European species, including White Sea and Baltic herring.

Other diseases of herring, particularly those of bacterial etiology, deserve intensive ecological and laboratory study. Systemic bacterial infections are not uncommon in immature herring, and have been responsible for mass mortalities in experimental tanks. Artificially high temperatures, near the upper limit of tolerance of herring, were accompanied by extensive mortalities of experimental fish exhibiting characteristic symptoms of bacterial disease described by Sindermann and Rosenfield (1954*a*) as "bacterial tail rot". Snieszko (1962) has demonstrated that furunculosis and other bacterial diseases of fresh-water fishes can be influenced to a marked degree by temperature, and that even slight increases in temperature can increase mortality rates significantly.

Diseases in marine species result from a complex and constantly changing relationship between factors extrinsic and intrinsic to the individual and the population. Extrinsic or environmental influences on occurrence and effects of diseases may in some instances be marked, but have been inadequately studied, particularly in pelagic species. A continuing investigation of disease in Atlantic herring, *Clupea harengus, harengus*, has provided some information about environmental effects on three diseases: "pigment spot" disease caused by a larval trematode (*Cryptocotyle lingua*); myxosporidian disease caused by *Kudoa clupeidae*, and fungus disease caused by *Ichthyosporidium hoferi*.

Larval trematode abundance was found to decrease markedly from west to east along the northern New England coast. Fewer parasites occurred in herring from eastern Maine and New Brunswick than in herring from western Maine. Incidences of the larval trematode in *Littorina littorea*, the snail first intermediate host, did not have a corresponding geographic distribution. Experimental studies demonstrated a critical role of temperature in determining emergence of infective cercariae from the snail, and a relationship of abundance of the parasite in herring and environmental temperatures has been proposed.

Myxosporidian distribution and abundance followed a trend much like that of the larval trematode, with fewer infections in eastern regions of the Gulf of Maine than in western. The parasite did not occur in one-year-old fish taken on the eastern coast during eight years of sampling, but was abundant in fish of the same age taken on the western coast. The larger picture of occurrence of this parasite in the western North Atlantic provides further indication of a direct relationship of parasitism with environmental temperature, although other factors may be involved.

Epizootics of the fungus disease have occurred repeatedly in western North Atlantic herring. While knowledge about the possible influence of environmental conditions on prevalence of the disease is incomplete, it has been demonstrated experimentally that increasing infection pressure (increased dosage of spores) results in increased abundance and severity of the disease in herring. Intrinsic factors such as individual and population resistance are undoubtedly important also, and individual variations in susceptibility have been demonstrated.

Other instances of changes in occurrence of disease with locality and age of the fish have been observed during the course of this research. Surveys of disease incidence, life cycle studies, experimental studies of the role of environmental variables; all should prove to be fruitful areas for future investigations. Concurrent studies of immune responses and variability in resistance should provide a broad basis for understanding the role of disease in herring populations.

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FEDERAL FISHERIES RESEARCH EXPANDING IN MAINE

By BERNARD E. SKUD

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U.S. Bureau of Commercial Fisheries Biological Laboratory
Boothbay Harbor

New funds for lobster research and contracts with research agencies have highlighted this year's program at the U.S. Bureau of Commercial Fisheries Biological Laboratory in Boothbay Harbor.

Monies were received last July for the initiation of the lobster studies, and field and laboratory work is progressing on schedule. Two contracts have been made, one with the University of Rhode Island to conduct research on the body proportions of lobsters, and another with the Maine Dept. of Sea and Shore Fisheries to conduct research on the soft-shell clam.

The Bureau's staff, which now numbers 43, is housed on McKown Point in Boothbay Harbor. The main laboratory is in the original Federal hatchery building that was completed in 1905. Over the years, this building has been refurbished and, though not large enough for the entire staff, it houses modern offices and a library, as well as laboratory space and the experimental sea water tanks.

Other office and laboratory space is provided in former hatchery residences. This is the base of operations from which the biologists work along the Maine coast, east of Nova Scotia and to the continental shelf south of Cape Cod. Scientific cruises in local waters between Casco Bay and Pemaquid are conducted aboard the laboratory's 40-foot Phalarope II.

Other Bureau vessels are utilized on longer cruises. The 60-foot Rorqual out of Gloucester is used for cruises from Cape Ann, Mass., to Eastport. The 110-foot Delaware, also from Gloucester, and the 180-foot Albatross IV from Woods Hole are used on cruises to Georges Bank and the edge of the continental slope. Future plans call for a new 70-foot vessel to be assigned at Boothbay Harbor. The design of this vessel was recently completed by John G. Alden and Co., Boston.

Two-thirds of the Laboratory's $600,000 annual budget is directed toward herring research. This effort includes the study of immature herring which are utilized in the Maine sardine fishery.

Each year the Laboratory's scientists meet with Russian and Canadian scientists to discuss research results. These meetings are under the auspices of the International Commission for the Northwest Atlantic Fisheries, and this year will be in Halifax.

One of the significant achievements to be discussed this year by the Bureau biologists will concern herring larvae. With new gear designed at the laboratory, scientists have been able to capture these tiny ½" fish soon after they have been hatched from eggs and to trace their growth throughout the winter to a size of 1½-2" by early spring.

This information is important to herring biologists the world over because so little is known about this stage of the herring's life history; and its significance to the Maine Sardine Industry is that these findings offer the possibility of predicting sardine abundance a year or two in advance.

The need for such prediction was emphasized in 1961 and again in 1964 when the supply of sardines available to the fishermen was low. Advance notice of the abundance of fish would permit canneries to pack accordingly and maintain a consistent supply of their product for the markets.

Another of the items scheduled for discussion at the Halifax meeting is the 1964 herring catch of the Russians on Georges Bank. In 1961, their catch was 67,000 metric tons and it climbed to 150,000 metric tons in 1962.

Their catch in 1963 included 107,000 metric tons of hake as well as 97,000 tons of herring. This diversification in species is expected to continue, although herring is still a highly prized species. This is evidenced by the Russian catches of herring off the coasts of Norway, Ireland, and in the North Pacific.

Past work by the Bureau on soft-shell clams has stressed the importance of basic biology, and this is incorporated in the new contract with the Maine Dept. of Sea and Shore Fisheries. Specifically, the state scientists will study the effects of environmental changes on clam behavior and activity, utilizing this information to improve the efficiency of the new cleansing method developed by the department.

The initial emphasis of the Federal Laboratory's lobster research is on the offshore populations. Two offshore cruises were conducted last fall and two were made this spring aboard the Albatross IV. The main purpose of these cruises is to determine the relationship, if any, between inshore and offshore lobsters. This problem is being approached in several ways, one of which is to compare the biochemical characteristics of the blood of both populations.

Three techniques—immunodiffusion, immunoelectrophoresis, and starch gel electrophoresis—will be used for this testing. These are methods which have been successfully used to distinguish populations of fish — such as salmon, tuna, and sardines.

Another method of comparing populations is to measure various body proportions of the lobsters. The analysis of such data has been contracted to the University of Rhode Island's Narragansett Marine Laboratory, where computer processing will hasten the results of this phase of the reasearch.

Animal associates of lobsters also can be useful indicators of population identity and migration tendencies; and this is another approach carried on in Boothbay Harbor. "Baggage tags," such as barnacles and other organisms which are attached to the lobster shell, as well as internal "freeloaders" can often be used to deduce the general environment from which a lobster has originated.

The normal range of these natural tags is often restricted and if a number of these organisms are found far from "home" attached to lobsters, deductions can be made about the lobster's geographic origin and its migratory route.

Artificial means of tagging or marking lobsters is another object of the laboratory studies. There is a particular need for a tag that will not be lost when the lobster sheds its shell. A number of tags have been utilized in the past, but these have only provided data for short-term experiments as the tag is cast along with the shell during the molting process.

Much more information can be obtained if it is possible to devise a tag that will be retained after molting. Testing these tags is a prolonged process as the scientists must be certain that the tags are not detrimental to or change the behavior patterns of the lobsters.

The information gained from these studies—along with other research on age, growth, environmental requirements, lobster larvae, and hydrography—will provide the basis for determining the relationship between inshore and offshore populations. The program is designed to utilize a number of avenues to solve this question, rather than relying on a single approach.

The scientists are not out to prove or disprove existing theories, rather they will attempt to validate or correct them; and certainly the people participating in the lobster fishery can and have provided much valuable information that will assist the scientists in this task.

The knowledge gained by experienced lobster fishermen is not the type found in scientific texts, and the biologists profit greatly by their contacts with the fishermen. It is cooperation of this type that will enhance and hasten the fruits of the expanded fisheries research at the Laboratory in Boothbay Harbor.

PORTLAND PRESS HERALD, State of Maine Edition, July 3, 1965

Reprinted from Science, May 28, 1965, Vol. 148, No. 3674, pages 1252-1254

Fish Immunogenetics Research

Early in this century, medical scientists in Japan pioneered hematological, immunogenetic, and serological studies of fish. About 25 years ago, the work was undertaken and amplified by biologists, particularly by a number of Japanese and U.S. investigators working in the fields of commercial fisheries and university research. The work may be categorized as: morphological studies of the blood corpuscles of various fishes, physiological and pathological studies of fish blood, and immunogenetic studies of the races and phylogeny of fishes.

Although the fish faunas on both coasts of the Pacific Ocean are in part closely linked, and although biologists in both Japan and the United States are active in the field of fish-blood research, until recently there have been few formal efforts to engage in investigations on an international basis.

From 16 to 20 November 1964, a planning meeting for hematological, immunogenetic, and serological studies of fish was held at the East-West Center of the University of Hawaii, Honolulu, under the auspices of the United States–Japan Cooperative Program in Science. Participants included five Japanese scientists, seven United States scientists, a representative of the National Science Foundation, and an interpreter from the State Department. Cochairmen of the meeting were L. M. Sprague (U.S. Bureau of Commercial Fisheries, Honolulu) and Yasuo Suyehiro (University of Tokyo). The meeting was divided into six working groups, which made specific proposals.

Group No. 1, composed of Nobuyuki Kawamoto (University of Nihon), G. J. Ridgway (U.S. Bureau of Commercial Fisheries, West Boothbay Harbor, Maine), and J. E. Wright (Pennsylvania State University), suggested that Ridgway and Wright cooperate with Ryozo Yuki (Hokkaido University) in fundamental studies of the inherited characters of serum proteins of fishes and on serological studies of salmonoids. Specific areas of cooperation included: (i) exchange of reagents and reference material, (ii) maintenance by Ridgway and Wright of rainbow trout of known inheritance to serve as reference populations, (iii) exchange of ideas and information and (iv) travel to Japan and the United States for collaborative research.

Group No. 2, composed of Takashi Hibiya (University of Tokyo), Suyehiro, and Wright, in considering studies of the blood of cultured fishes, agreed that the primary area of common interests concerns the relation between growth and reproduction in cultured Salmonidae, particularly *Salvelinus fontinalis*; of particular interest are such blood characteristics as hematocrit values, hemoglobin measurements, and quantitative and qualitative measurements of serum components. The influences of water quality, nutrition, age, sex, season, disease, and stress on these blood characteristics are to be determined and related to growth and reproduction. The main practical object of this research is to determine through blood studies the best artificial feed for cultured fishes.

Group No. 3, composed of Suyehiro, Sprague, and Ridgway, considered studies of the serology and immunogenetics of the carp *Cyprinus carpio*, one of the most geographically cosmopolitan fresh-water fishes; both domestic and wild carp are found all over the world. Easily adapted to laboratory conditions, it is an ideal animal for studies of serum-protein variations that occur in various strains or races (subpopulations), as well as for genetic studies of the patterns of inheritance of blood-group antigens. It was agreed: (i) to compare serum-protein constituents from carp collected in various geographic areas in the United States and Japan, with analysis to be carried out largely by Japanese scientists, and (ii) to carry out basic studies of the inheritance of red-blood-cell antigens by use of classical techniques developed in studies of man and of cattle and other domestic species.

Group No. 4, consisting of J. E. Cushing (University of California, Santa Barbara), Suyehiro, and A. M. Vrooman (U.S. Bureau of Commercial Fisheries, La Jolla, California), proposed that, in view of their common interest in conducting serological studies on mackerel, scientists in both countries cooperate closely in the development of reagents and techniques. The group recommended that a start be made on cooperative studies on gobioid fishes by the exchange of live specimens of the haze, *Acanthogobius flavimanus* (T. & S.), from Japan, and the mudsucker, *Gillichthys mirabilis* Cooper, from California. Vrooman and Cushing have investigated the mudsucker sufficiently to show that normal guinea pig serum recognizes an individual erythrocyte antigenic variation, a discovery that could form the basis of expanded serological investigations of the gobioid group.

Also proposed was a cooperative study of the pearl oyster and other bivalves. Under this study, Cushing would spend a summer in Japan learning the techniques of pearl culture, knowledge of which would make possible study of the relative effectiveness of transplants of different kinds of mantle and other tissue among oysters. Modifications of this technique would also be useful in transplantation experiments on other forms of marine invertebrates. Finally, it was agreed that the Japanese should collect eye lenses of identified mackerel and send them to Vrooman, who would prepare electrophoretic patterns of them as well as patterns from identified U.S. mackerel.

Group No. 5, composed of Kazuo Fujino (U.S. Bureau of Commercial Fisheries, Honolulu), James Joseph (Inter-American Tropical Tuna Commission, La Jolla, California), and Akimi Suzuki (Tokai Regional Fisheries Research Laboratory, Tokyo), discussed population genetics of Pacific bigeye and albacore tunas with reference to studies of erythrocyte antigens. It was agreed to emphasize basic studies on relations between blood groups and other biological factors that may play important roles in microevolutionary development of different subpopulations. The purpose would be to monitor the effects that these biological factors may have on the interpretation

of serological findings as they are related to population identification. Bigeye tuna were chosen as the initial object of the studies because blood-grouping and other basic information is available; moreover, this is one of the largest pelagic fisheries in the world. It was agreed that cooperation must take the form of frequent exchange of reagents, erythrocytes, and information. The principals are to meet when practicable in Hawaii and Japan to standardize reagents and techniques of testing.

Group No. 6, composed of Fujino, Suzuki, and Vrooman, proposed further efforts toward cooperative studies of the erythrocyte antigens of U.S. and Japanese sardines.

The meeting as a whole recommended that a symposium on immunogenetic and serological methods be held at the 11th Pacific Science Congress (Tokyo, 1966). The meeting noted that exchange of scientists and students between the two countries is essential for the promotion of a cooperative program; asked that such materials as blood, serum, and other tissues be exchanged; recommended the training of young scientists in the fields of fish hematology, immunogenetics, and serology in Japanese and U.S. universities; and sought to encourage active participation of workers in these fields in meetings of national and international societies. Documents relating to current research in both countries were distributed and briefly discussed.

Participants not members of the working groups were Heihachiro Miyayama (Japanese Ministry of Education), N. P. Neureiter (National Science Foundation), and Ichiro Nishimura (U.S. Department of State).

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JOURNAL OF GEOPHYSICAL RESEARCH VOL. 70, NO. 2 JANUARY 15, 1965

Sea-Surface Temperature Anomaly Study of Records from Atlantic Coast Stations

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Abstract. This study covers sea-surface temperature anomalies at 27 Atlantic coast stations from Eastport, Maine, to Key West, Florida, for the years 1873–1961. The anomalies were computed using as a common base period the years 1950–1959. A secular warming trend peaking in the early 1950's is demonstrated. This trend was strongest in the north and diminished progressively toward the south, where a slight cooling trend was present at Key West. Seasonal differences in the trends are also pointed out. A comparison between the east and west coasts of the United States, and between the English Channel and the east coast of the United States, shows that a partial negative correlation exists between the anomalies of the east and west sides of the oceans. This negative correlation is greatest between northern stations and becomes less toward the south, where a positive correlation may exist at times. A short review is given of previous work on climatic change in the North Atlantic, and of work on the differences between the two sides of an ocean and their causes.

Introduction. For many years a climatic change has been evident in the North Atlantic region. *Kincer* [1933] noted a general trend toward higher mean annual air temperatures over North America. Changes in the marine biota of the European Arctic during the 1920's and 1930's, especially the development of a cod fishery in west Greenland, prompted many investigations of the causes; these were summarized by *Jensen* [1939], who concluded that both sea and air temperatures had risen. *Smed* [1947] strengethened this conclusion by an analysis of sea-surface temperature records around south Greenland; he noted that warming had occurred, beginning about 1920. Further evidence of climatic change in the Arctic, and of concurrent changes in the biota, was given in 1949 in *Rapports et Procès-Verbaux des Reunions,* vol. 125, part 1, Conseil Permanent International pour l'Exploration de la Mer.

Ahlmann [1948] brought together much information indicating a general climatic warming and stated that the temperature of the North Atlantic had increased since the beginning of the century. *Hachey and McLellan* [1948] presented data showing a warming trend in the surface waters of the Canadian Atlantic, as did *Smed* [1949] for the waters of the northeast Atlantic. *Smed* [1952] later presented data showing a general warming in the Faroes. *Lauzier* [1952, 1953, 1954] compiled data on the sea-surface temperatures at 17 Canadian Atlantic coast stations and commented on the general trend to higher temperatures in the early 1950's. *Rodewald* [1956] also demonstrated this warming of Canadian waters and extended his analysis to cover the area as far south as Charleston, S. C.

Changes in the commercial fisheries and the marine biota of New England were analyzed in relation to a climatic warming by *Taylor et al.* [1957], who also showed that the entire water column in the Gulf of Maine had increased 1–5°F since 1912–1926. This warming of deep waters was also demonstrated by *Lauzier and Trites* [1957] for the Laurentian Channel.

Bjerknes [1959] wrote on the warming in the North Atlantic. Using the means of the periods 1890–1897 and 1926–1933, he found a maximum surface temperature increase along the Gulf Stream axis from Cape Hatteras to the Grand Banks and a belt from Ireland to the Labrador Current that had not been warmed; north of this belt warming had started about 1920. *Southward* [1960] later noted a rise of the mean annual surface temperature in the English Channel. *Lauzier and Hull* [1961] brought the Canadian Atlantic coast station data up to 1959 and showed that a downward trend in surface temperatures had set in after a peak in the early 1950's.

Rodewald [1963] analyzed the surface temperature for the North Atlantic for the decade 1951–1960 and demonstrated that the early 1950's were characterized by warming in the western North Atlantic which extended as far east as the Azores, and by a cool zone between 50–55°N. The late 1950's were characterized by warming of the northeast Atlantic, the disappearance of warming in the western North Atlantic, and a spreading of the cool zone to the southwest.

The present study was undertaken to further document the environmental changes of this century, to estimate the gross variability of the sea-surface temperature along the Atlantic coast of the United States, and to estimate the secular trends along the coast and their geographic variation. Monthly and annual temperature anomalies were computed at 27 coast stations and light ships (see Figure 1).

The extent of existing data for 95 stations along the east coast of the United States is shown in Figure 2. Some of these records extend from the 1870's to the 1960's, but all contain gaps of varying magnitude. The 27 stations chosen for this study include those with substantially complete records for the 1950's and several others with exceptionally long records. It is regrettable that the early enthusiasm for collecting environmental data (inspired by the old U. S. Commission of Fish and Fisheries) lapsed during the first part of this century and was not revived until recently. As a consequence, almost 68% of the total east coast record consists of segments less than 5 years long.

Temperature data were obtained from publications of the *U. S. Coast and Geodetic Survey* [1955, 1960] and the U. S. Fish and Wildlife Service [*Bumpus*, 1957*a*, *b*; *Day*, 1959*a*, *b*, 1960]. Additional data for the period January 1959 to September 1960 were obtained from the files of the U. S. Coast and Geodetic Survey.

Temperature anomalies. Sea-surface temperature anomalies at each station were computed as the difference between each monthly (or annual) mean and the monthly (or annual) mean for the base period 1950–1959. Positive anomalies indicate warmer conditions, negative anomalies cooler conditions, than the mean of the 1950's. Annual anomalies are presented in Figure 3, and a time-geographic plot of the annual anomalies in Figure 4. The lengthy monthly anomaly graphs have been published separately [*Stearns*, 1964].

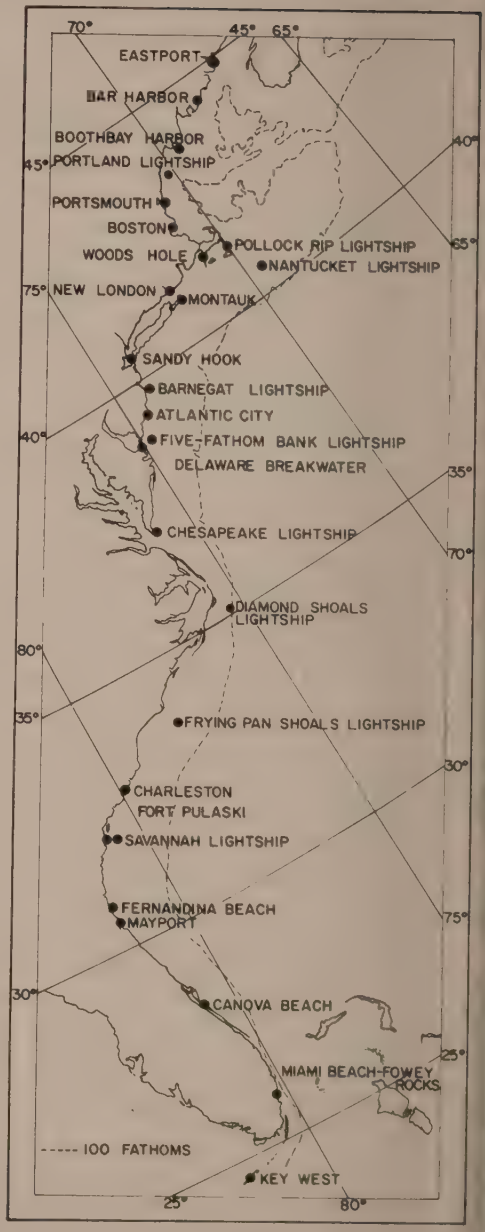


Fig. 1. Location of stations used in study.

Methods used were those of *Robinson* [1961], who has presented similar data for the Pacific

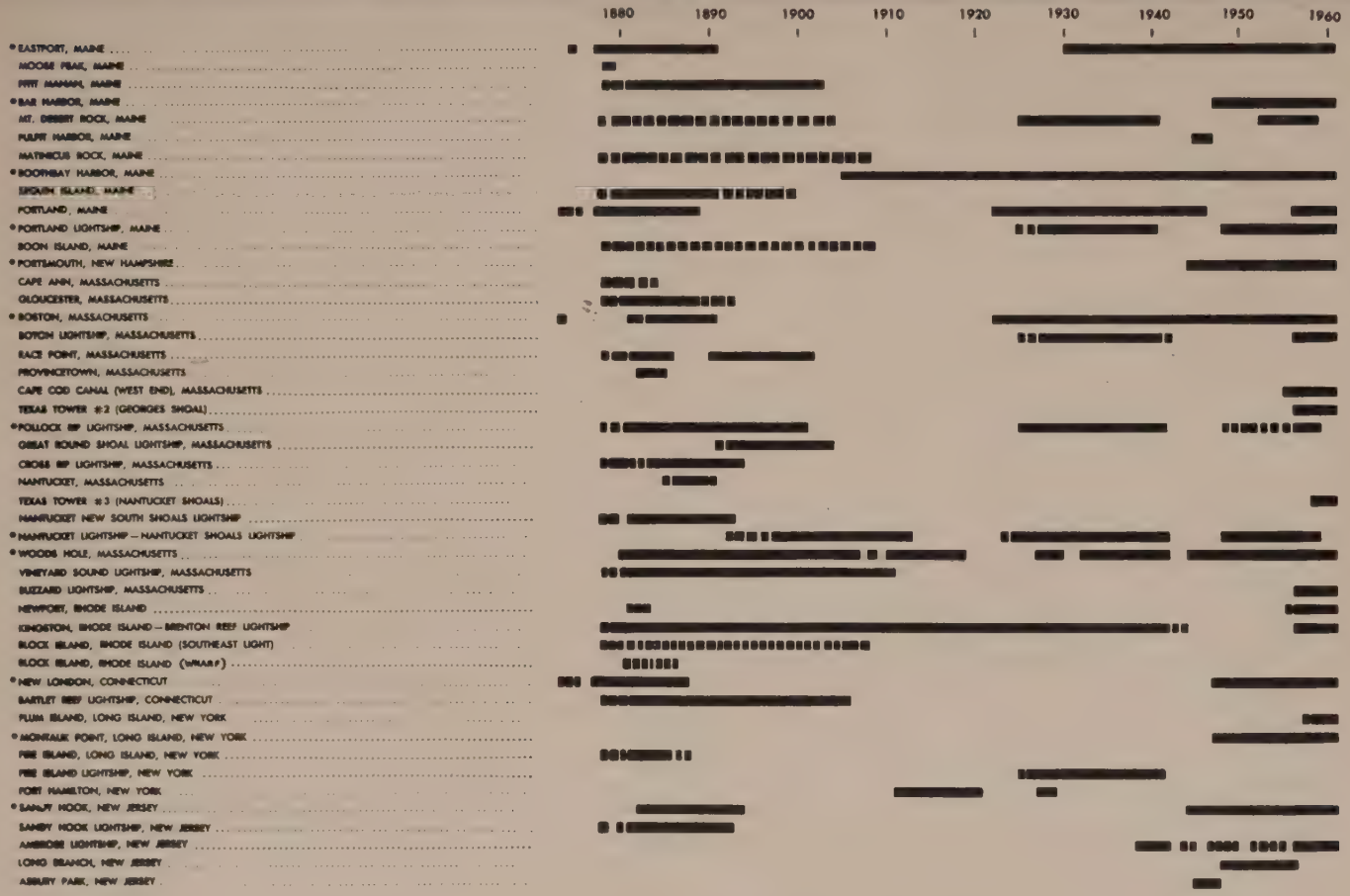
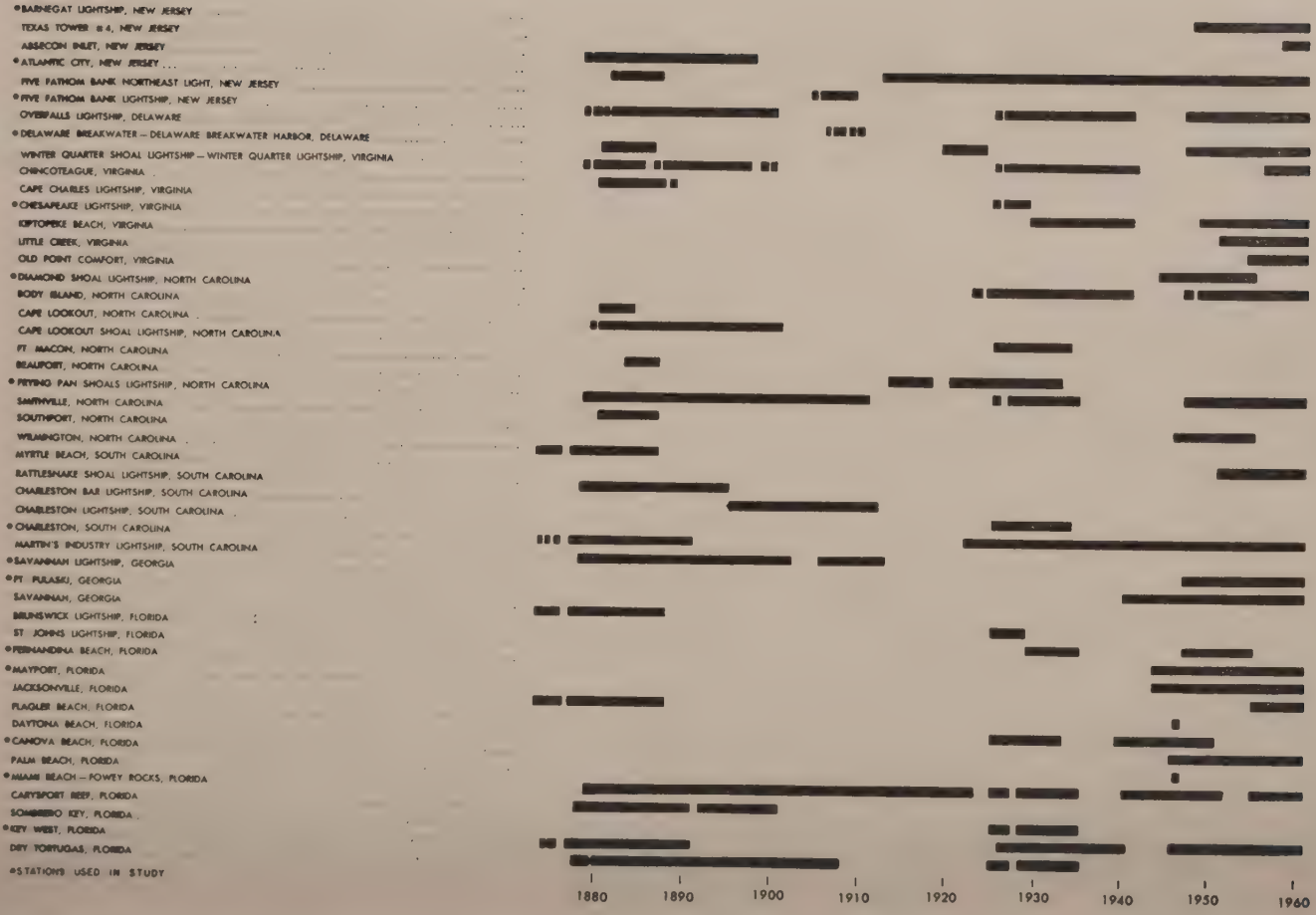


Fig. 2. Length of sea-surface temperature records at Atlantic coast stations.



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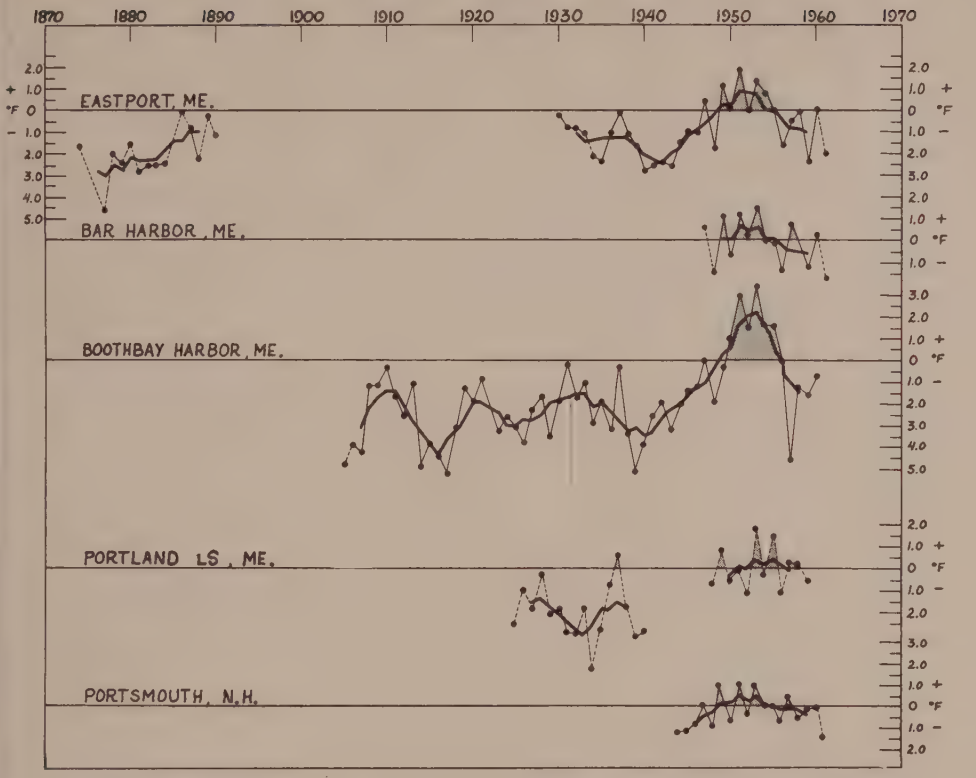

Fig. 3. Annual sea-surface temperature anomalies. Light solid line: annual anomalies based on complete yearly records. Dashed line: annual anomalies based on incomplete yearly records (estimates). Heavy solid line: 5-year moving average.

coast of North America [see *Scripps Institution of Oceanography*, 1960]. A common base period of 1950–1959 was used in order to maintain consistency with Robinson's analysis (so that the two coasts could be compared) and because the majority of Atlantic coast stations with recent records have most of these years in common (Figure 2). It would not be valid to compare anomalies computed from long-term means at individual stations because the length and completeness of the records vary greatly.

The validity of some anomalies of small magnitude may be questioned because (1) the means used for computation were derived from observations of various degrees of accuracy and precision, taken at various times of day, (2) the base period records are complete at only 9 of the 27 stations (the base period record is 99% or more complete at 13 stations, 90% or more complete at 19 stations, and 80% or more complete at 24 stations), (3) several stations were relocated during their history (especially Nantucket and Frying Pan), and (4) one station consists of combined records from nearby localities (Miami Beach–Fowey Rocks). Relocated and combined stations were included among the 27 selected for analysis because of their useful geographic position and/or their long historical records (see Figures 1 and 2).

The annual anomaly graphs (Figure 3) show several maximums and minimums, with a definite warming trend peaking in the early 1950's. This trend is most pronounced in the north, where the vast majority of years before the late 1940's were colder than the mean of the base period. *Rodewald* [1956] has previously noted this southward decrease in the warming trend along the coast.

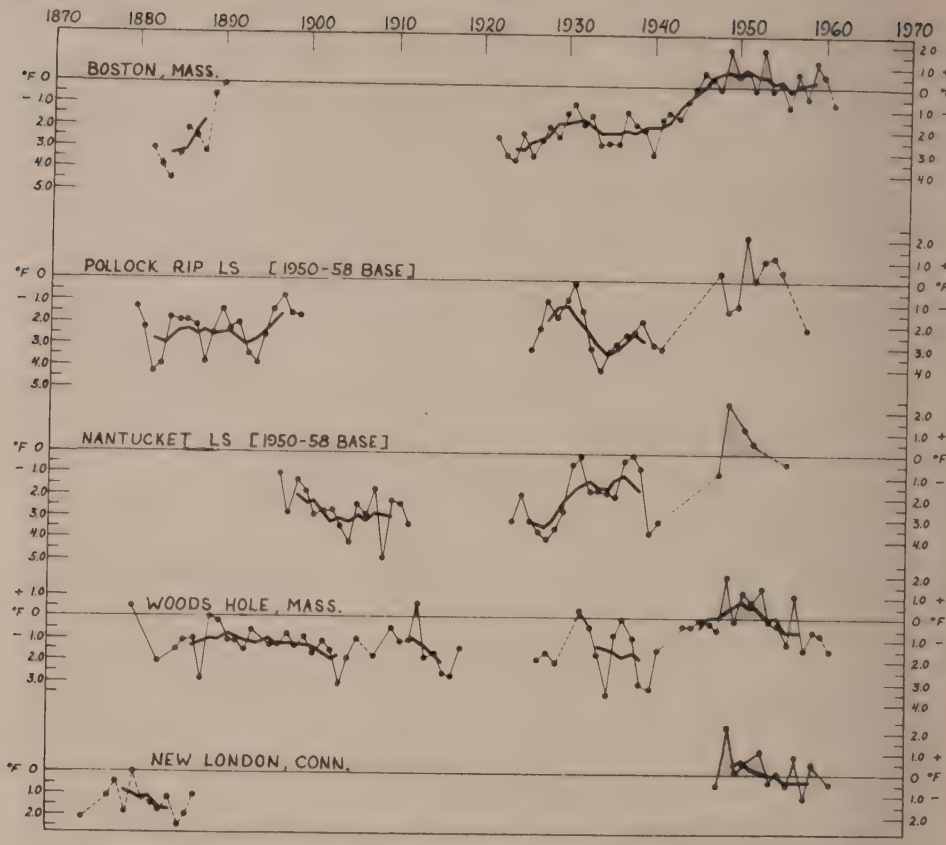

Fig. 3. (Continued)

That some of the warming trend is a result of population increase and industrial concentration in coastal cities seems possible [see *Mitchell*, 1953]; but the sudden increase at a majority of the stations in the 1940's and the cooling trend in the late 1950's argues for other, more primary, causes.

For further testing of this north-south difference a frequency analysis of monthly anomalies was made for five stations spaced along the coast from Maine to Florida (Table 1). These stations were selected for completeness of record during the base period and for their exceptionally long records. The most obvious relation between these stations is a progressive north-south change from negative to positive mean anomalies. A t test made on the mean anomalies of adjacent stations [*Dixon and Massey*, 1957, pp. 123–124] showed that the mean anomalies are significantly different at the 99% level.

This indicates that the recent secular warming trend along the coast becomes progressively more important from the north to the vicinity of Charleston. Between Charleston and Key West this trend seems to be unimportant, although data for the years before the 1940's are lacking. In the vicinity of Key West a slight cooling trend seems to have been dominant, although *Brown* [1963] has found a 'marked increase of air and sea temperature during the present century' throughout the tropical Atlantic, from 30°S to 30°N. He states, however, that 'the character of the fluctuations has varied considerably over the area.'

A frequency analysis of the February and August anomalies was also made for the five

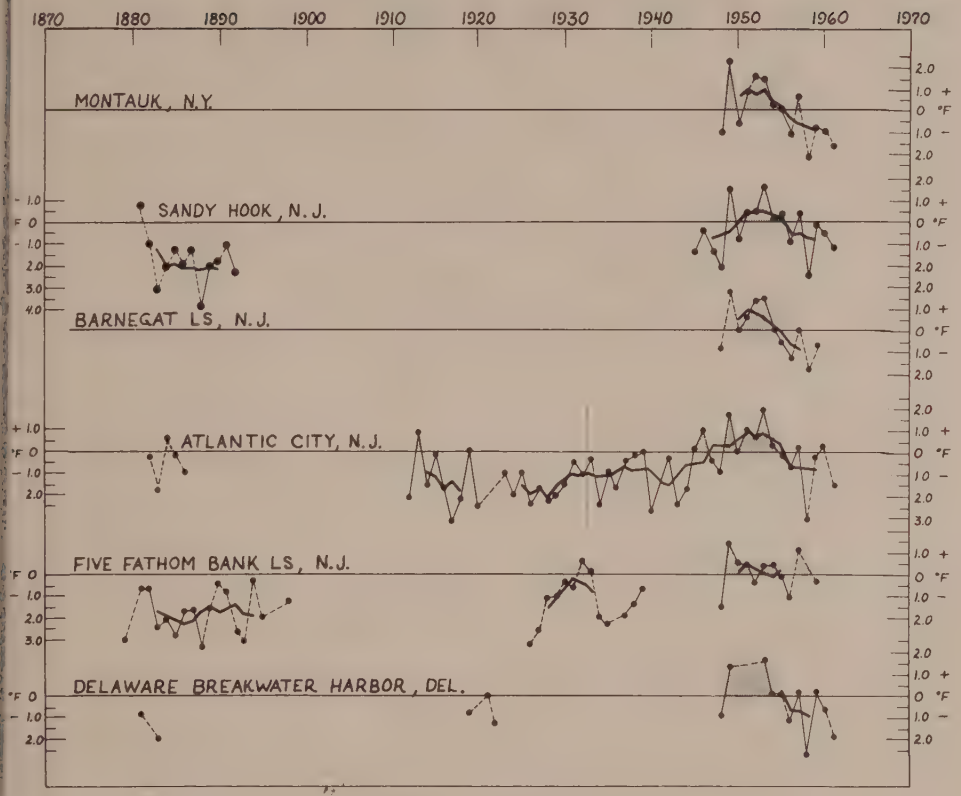

Fig. 3. (Continued)

TABLE 1. Frequency Analysis of Monthly Anomalies (Degrees Fahrenheit)

Station	Total Monthly Anomalies			August Anomalies			February Anomalies		
	Number of Anomalies	Mean Anomaly	Standard Deviation	Number of Anomalies	Mean Anomaly	Standard Deviation	Number of Anomalies	Mean Anomaly	Standard Deviation
Boothbay	665	−2.79	3.17	54	−0.41	1.67	55	−4.91	3.21
Woods Hole	792	−1.19	2.10	65	−0.84	1.49	60	−1.68	2.29
Atlantic City	624	−0.81	2.34	53	−0.19	2.59	53	−1.72	2.74
Charleston	643	−0.26	2.41	55	−0.65	1.14	53	−0.77	3.39
Key West	513	+0.46	1.95	43	−0.10	1.08	43	+1.16	3.17
Total				270	−0.45	1.69	264	−1.72	3.53

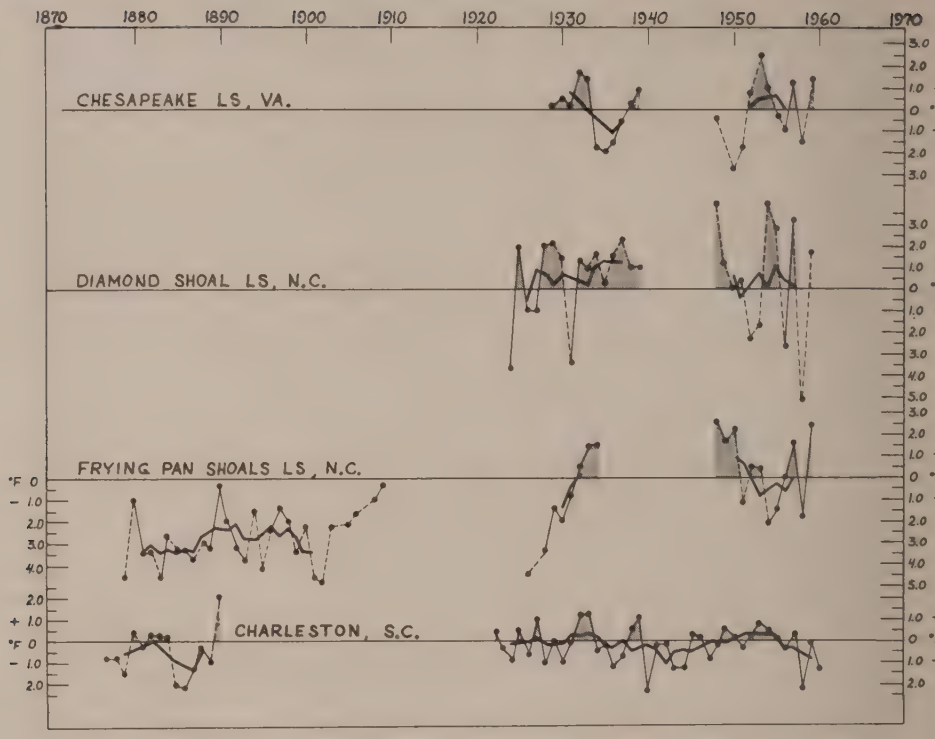

Fig. 3. (Continued)

stations (Table 1). Although the mean coast-wide anomaly is negative in both August and February, February had the larger mean anomaly. This suggests that the warming trend was a product of mild winters more than of warm summers, a fact which has been noted by others [see *Kincer*, 1933; *Taylor et al.*, 1957].

Another t test made on the mean August and February anomalies of adjacent stations showed that the mean August anomalies are not significantly different between stations and that the mean February anomalies are significantly different (at the 99% level) only between Boothbay and Woods Hole and between Charleston and Key West. It therefore appears that for August there has been a slight secular warming along the whole coast (including Key West) but that for February at least three different trends can be identified: (1) a very strong warming trend in the Gulf of Maine (and possibly in the Canadian Atlantic waters); (2) a weak to strong warming trend along the Middle and South Atlantic coasts, which weakened from north to south; and (3) a moderate cooling trend around Key West.

The time-geographic plot of the annual anomalies (Figure 4) shows an interesting temporal progression of anomalies up the coast. Since about 24% of the annual anomalies are only estimates, and since the data are rather sparse before the mid 1940's, this graph should be interpreted as showing only gross relations, of which the following are apparent:

(1) Positive anomalies extending northward (*a*) to South Carolina in the 1880's, (*b*) to southern Florida in the late 1900's, (*c*) to southern New England in the early 1910's, (*d*) to Delaware Bay in the 1930's, and (*e*) to northern New England in the late 1940's and early 1950's.

(2) Negative anomalies extending along the whole coast during the 1890's, early 1900's, late 1910's, late 1920's, early 1940's, and late 1950's.

Coherence of temperature anomalies. *Robin-*

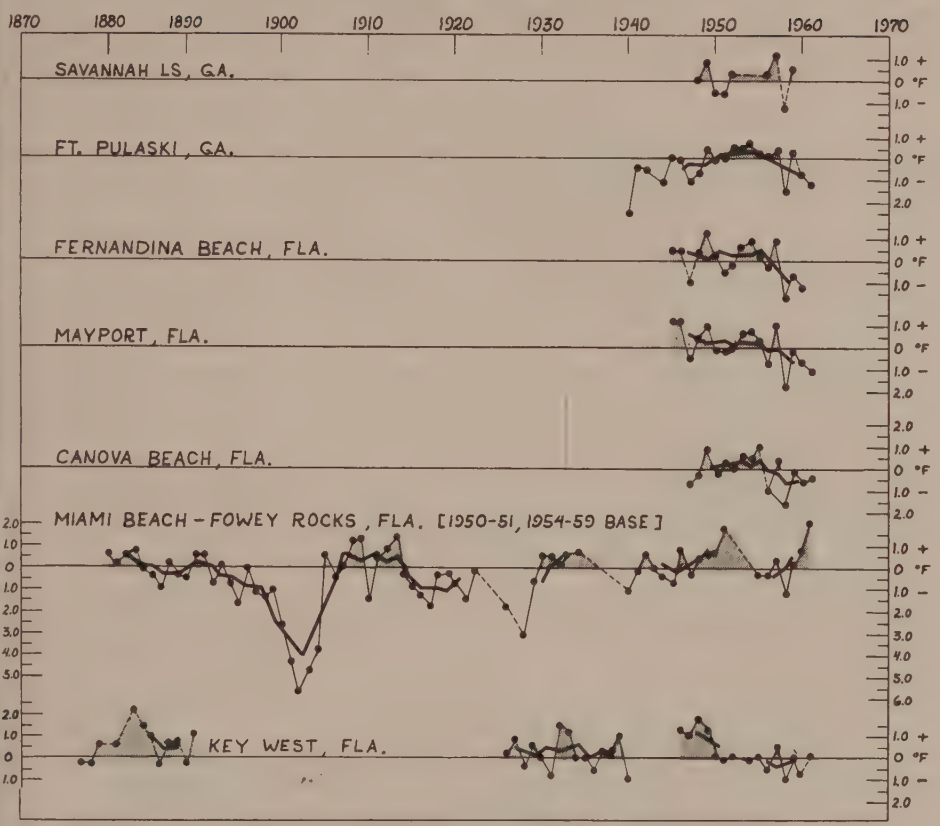

Fig. 3. (Continued)

Dixon's [1961] procedure (where coherence is defined as agreement in sign of anomalies) was followed in computing a table of coastwide coherence (Table 2). This table shows the temporal distribution of months that were colder or warmer than the mean of the 1950's along the whole coast. Determination of the significance of the coastwide coherence is based upon confidence limits for proportions, derived from the binomial distribution [*Dixon and Massey*, 1957, pp. 228–231, 413–416]. Data from 14 or more stations are available only for the years 1946–1961, and the data treated in the table are restricted to this period. Some 56.7% of the months of record have significant coherence. The coastwide coherence of the annual anomalies is significant in 50% of the years. Significant coherence is highest in the winter and spring and lowest in the summer and fall.

The persistence of coastwide coherence can also be seen from this table. The mean number of successive months with 95% significant coastwide coherence is 2.0, and the maximums are 7 months for positive anomalies and 8 months for negative anomalies. If we ignore the 95% significance criterion and consider only coherence between a simple majority of stations along the coast, the average persistence rises to 3.7 months, with maximums of 20 months for positive anomalies and 11 months for negative anomalies. The persistence of positive or negative anomalies at individual stations is considerably longer, as can be noted from the monthly anomaly graphs [*Stearns*, 1964].

As has been shown by *Rodewald* [1956, 1963], *Bjerknes* [1959], *Brown* [1963], *Mitchell* [1963], and others, and as has been indicated above, secular fluctuations in the sea-surface tempera-

Fig. 4. Time geographic plot of annual sea-surface temperature anomalies. Large dots: annual anomalies based on complete yearly records.

TABLE 2. Coastwide Coherence of Monthly Anomalies

Year	Month												
	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1946			+10/14	+10/14	−8/14	−14/14	−9/14	−8/14	−8/14	7/14	+13/14	+11/14	
1947	+10/14	−13/14	−12/14	−10/14	−14/15	−13/16	−10/16	−9/17	+20/23	+16/23	+13/24	−15/24	−9/15
1948	−21/26	−21/27	−16/26	−14/24	−17/25	−17/24	−16/26	−20/27	−14/24	−23/25	+23/25	+23/26	−19/27
1949	+22/26	+23/26	+20/25	+22/25	+21/25	+17/25	+24/26	+18/26	−17/26	+24/26	+17/25	+20/25	+25/27
1950	+24/25	+20/25	−17/24	−22/25	−17/24	−14/24	−21/25	−17/26	−21/25	+17/24	+20/23	+12/23	−15/27
1951	+13/25	−14/24	+20/25	+17/25	+15/24	+16/24	+20/25	+23/25	+23/25	+19/25	−20/25	+18/24	+18/26
1952	+20/23	+18/22	+17/24	+16/24	−15/25	+18/25	+21/25	+18/25	−13/23	−17/23	−21/25	+14/25	+17/25
1953	+18/23	+23/23	+22/23	+23/24	+20/22	+17/23	+20/25	+15/26	+13/24	+16/23	+16/24	+21/23	+22/23
1954	+16/23	+17/22	+17/25	+23/25	+16/24	+16/25	+13/24	−17/25	−15/23	+19/22	−15/23	−18/24	+17/24
1955	−14/26	−20/24	+21/25	+15/24	+17/24	−14/24	+22/25	+21/24	+15/24	+18/25	−15/24	−19/24	+15/25
1956	−25/26	+14/27	−22/27	−27/27	−21/26	−19/25	−22/26	−20/26	−20/25	−21/26	+16/27	+21/25	−24/26
1957	−13/24	+24/27	+22/27	+24/26	+25/26	+23/26	−14/24	−18/24	+19/23	−19/26	+14/25	+16/25	+22/24
1958	−16/24	−23/27	−21/26	−21/27	−20/24	−24/25	−21/25	−17/26	−13/24	−20/23	+13/25	−17/25	−23/25
1959	−22/25	−16/25	−21/25	−13/25	+16/24	−17/25	−13/25	+13/24	+16/26	+20/23	−14/24	+15/25	−14/25

TABLE 2. (Continued)

Year	Month												
	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1960	$+\frac{11}{19}$	$+\frac{10}{19}$	$-\frac{19}{19}$	$-\frac{13}{19}$	$+\frac{12}{19}$	$+\frac{11}{19}$	$-\frac{10}{19}$	$+\frac{12}{19}$	$+\frac{9}{17}$	$+\frac{11}{18}$	$+\frac{16}{19}$	$-\frac{17}{18}$	$-\frac{13}{18}$
1961	$-\frac{16}{18}$	$-\frac{16}{18}$	$\frac{9}{18}$	$-\frac{14}{18}$	$-\frac{14}{18}$	$-\frac{15}{18}$	$-\frac{16}{18}$	$-\frac{12}{17}$	$+\frac{12}{15}$				
	53.3*	73.3	75.0	50.0	56.2	56.2	56.2	37.5	37.5	73.3	40.0	53.3	50.0

Legend.

+ Majority of stations with positive anomalies.
− Majority of stations with negative anomalies.
Numerator is the number of stations agreeing in sign of anomaly.
Denominator is the total number of stations.
Numbers underlined are significant at the 95% level.
* Figures at bottom of table are percentage of years with 95% significant coherence.

ture field are likely to vary spatially as well as temporally. It is thus surprising that Table 2 shows as much coherence as it does. A larger degree of coherence between stations could probably be demonstrated if smaller segments of the coast were selected for analysis.

Comparison of east and west coasts. A comparison of the data in Table 2 with similar data given by Robinson for the west coast gives an impression that coastwide coherence on the two coasts is negatively correlated. For example, when a majority of stations on one coast had monthly anomalies of one sign, the majority of stations on the other coast had the opposite sign 59.3% of the time. When the two coasts each had 95% significant coastwide coherence in the same month, they had anomalies of opposite sign 65.1% of the time. On the basis of the binomial distribution both of these percentages are significant. A month by month comparison between Departure Bay, Vancouver Island, British Columbia [data from *Robinson,* 1961], and Boothbay for the period 1920–1959 shows that the two stations disagreed in sign of anomaly 62.6% of the time, which is significant at the 95% level. These two stations had 95% significant disagreement in all of the decades of the period except the 1920's. Another month by month comparison for the same period between Pacific Grove, California [data from *Robinson,* 1961], and Atlantic City shows only a 52.4% disagreement, which is not significant. These two stations had significant disagreement in the 1940's and significant agreement in the 1920's.

A comparison between the signs of the annual anomalies for the period 1947–1959 for International Station E1, in the English Channel [data from *Southward,* 1960], and five United States Atlantic coast stations shows 95% significant disagreement for Boothbay, nonsignificant disagreement for Woods Hole, Atlantic City, and Charleston, and nonsignificant agreement for Key West.

This partial negative correlation between the east and west coasts of the oceans was noted by *Walker* [1932], who commented that warm winters in Scandinavia and cold winters in Greenland and Labrador appear to be associated. *Hanzawa* [1957, 1958*a, b*] later demonstrated a negative correlation between sea-surface temperature anomalies on the east and west sides of the Pacific. *Bjerknes* [1959] and *Rodewald* [1963] have drawn sea-surface temperature anomaly maps for the North Atlantic that show not only this east-west disagreement but also the geographic and, to a limited degree, the temporal distribution of anomalies. The same has been done for the North Pacific by *McGary* [1960] and the *Bureau of Commercial Fisheries* [1962]. *Brown* [1963] has commented upon variations in air temperature over the Atlantic which are of opposite character over the eastern and

'estern parts of the ocean,' and *Mitchell* [1963] as drawn world-wide air temperature anomaly naps which show the differences between the ast and west sides of both the Atlantic and 'acific.

These differences have been explained by nost workers in terms of the general atmos-heric and oceanic circulation. According to *Hanzawa* [1958*b*], 'when a single negative pres-ure anomaly pattern is dominant over the North Pacific, the intensity of the Aleutian Low s believed to be above normal and the Pacific High below normal. In such a case water temper-ture anomalies on the American side show large positive values and those on the Japanese side arge negative values.' *Hanzawa* [1957, 1958*a*] further relates this negative atmospheric pres-ure anomaly to decreased oceanic circulation n the North Pacific, which, presumably, would allow cool water to move southward along the Japanese coast and warm water to move north-ward along the American Pacific coast. *Brown* [1963] makes similar comments concerning the Icelandic Low and the North Atlantic circula-ion. *Rodewald's* [1963] analysis of the North Atlantic in the 1950's seems to support the idea that an expanding Icelandic Low causes warm-ng in the northeastern Atlantic and cooling in the western Atlantic, but the details are quite complex. Both *Hanzawa* [1957, 1958*a*, *b*] and *Bjerknes* [1959] apparently associate positive sea-surface temperature anomalies on the west sides of the oceans with increased atmospheric circulation, whereas *Rodewald* [1963] notes that, at least for the late 1950's in the North Atlantic, negative anomalies on the west side were as-sociated with increased atmospheric circulation.

It should be pointed out that *Iselin* [1940; cited by *Stommel*, 1960, p. 175] suggests that an increased oceanic circulation (due to increased wind drag) could cause a contraction of the central oceanic warm water mass, thus with-drawing warm water from the coasts and caus-ing negative temperature anomalies on both the east and west sides of the ocean (a decrease would presumably cause positive anomalies on both coasts). *Stommel* [1960, p. 176] suggests that diminished wind drag would not cause a radial contraction of the circulation but might cause the peripheral isotherms to become deeper, thus presumably warming both sides of the ocean. Since sea-surface temperatures are con-trolled by a variety of interrelated factors, in addition to atmospheric and oceanic circulation, the feedback relations between the ocean and the atmosphere must be better understood be-fore an acceptable mechanism can be proposed. In view of the geographic and temporal varia-tions of the temperature anomalies demonstrated above, and by other workers, and the imperfect correlations between the coasts, it seems likely that all of the above mechanisms play their part.

Acknowledgments. Thanks are due Frances M. Fehrman who performed most of the laborious computations and tabulations connected with this study, Charles B. Taylor for access to the unpub-lished records at the Coast and Geodetic Survey, and J. Lockwood Chamberlin for his contribu-tions to the clarity of the presentation. Margaret K. Robinson reviewed the manuscript and offered many constructive comments.

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(Manuscript received June 15, 1964; revised September 23, 1964.)

Made in United States of America
Reprinted from COPEIA, 1965, No. 1, March 18
pp. 20–24

Description of the Larva and Familial Relationships of the Fish *Snyderidia canina*

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Description of the Larva and Familial Relationships of the Fish *Snyderidia canina*

Donald W. Strasburg

The larva of *Snyderidia canina* bears a prominent vexillum whose presence relates the Pyramodontidae to the Carapidae. Among the peculiarities of the adult are its black pigmented stomach accompanied by a black peritoneum, the transparent roof of its skull, its complex predorsal bone, and the simple structure of its caudal region. The last 2 features further link the Pyramodontidae and the Carapidae.

Introduction

ALTHOUGH only 3 specimens of the bathypelagic fish *Snyderidia canina* Gilbert have hitherto been reported, the species has been well described (Gilbert 1905, Gosline 1960), and much work has been done on its systematic position. *Snyderidia* is currently placed in the Pyramodontidae, an ophidioid family having affinities with the Carapidae (Smith 1955, Gosline 1960). The recent capture of 4 additional specimens, including a larva, by the U. S. Bureau of Commercial Fisheries Biological Laboratory in Honolulu, provides additional biological information on this rare fish, and also confirms its relationships with the Carapidae. The purpose of this paper is to describe the larva and compare it and the adults with representatives of other ophidioid families. Thanks are due Mr. Tamotsu Nakata, Bureau of Commercial Fisheries Biological Laboratory, Honolulu, for preparing the figures, and Dr. William A. Gosline, University of Hawaii, for advice and the loan of comparative material.

All 7 known specimens of *Snyderidia* were taken in deep water, but it is perhaps significant that the 6 larger specimens were captured relatively close to land, whereas the single larva was found on the high seas. To summarize distribution, the 309-mm holotype was captured 4.5 mi from Kauai (Gilbert 1905, U. S. Commissioner of Fish and Fisheries 1904), Radcliffe's 418-mm specimen (1913) was taken 3.9 mi from Sialat Point Light in the Philippines (personal communication from R. H. Kanazawa, U. S. National Museum), Gosline's 122-mm fish (1960) was found floating about 0.5 mi from shore where lava from a Hawaiian volcano was pouring into the sea (personal communication), my 207–212-mm adults were taken 8.9 mi off Oahu, and the 104-mm larva was captured 120 mi from Malden Island in the central Pacific Ocean. Apparently, the adults occur near land, while the young stages are more strictly pelagic.

Specific capture data on the present specimens are as follows. The larva was taken on 14 June 1962, at 0°39.0′ S, 153°31.0′ W. The time of capture was 1952–2030 hr (zone time), and the capture device was a 6-ft Isaacs–Kidd trawl fishing between the surface and 100 m. The 3 adults were captured on 7 May 1956, between 2015 and 2115 hr. The locality was 21°38.5′ N and 158°25.7′ W, and the gear a 10-ft Isaacs–Kidd trawl fishing from the surface down to about 140 m. All were fixed in formalin, subsequently stained with alizarin, and stored in 40% isopropyl alcohol.

Description

Fig. 1 shows the larval specimen. Its most significant feature is the ornamented vexillum immediately anterior to the dorsal fin. To my knowledge, a vexillum is found in only 1 other fish family, the Carapidae, where its presence has given rise to the name *vexillifer* stage for the distinctive individuals bearing it. As described by Arnold (1956), a vexillum differs from other kinds of filaments in being ornamented with tabs or lobes, and in being either deciduous or completely resorbed, except perhaps for its basal element (Strasburg 1961). The vexillum of this *Snyderidia* is 35 mm long. Its basal half consists of a pair of lepidotrichia, while its distal half is an unpigmented fleshy filament which bears 3 short tabs along its length and an elongate pennant at its tip. Other distinctive features of the larva are its greatly distended translucent abdomen and its tiny caudal fin.

Measurements made on this larva are as follows (in mm): head length 11.9, snout length about 2.8 (mouth open), eye diameter 2.8, width of fleshy interorbital 2.2, greatest depth of body (at vexillum) 14.0, snout to

Fig. 1. Vexillifer larval stage of *Snyderidia canina*. Standard length 104 mm.

level of anus 16.0, snout to vexillum 11.5, snout to dorsal origin 11.9, longest dorsal ray 4.6, longest anal ray 6.1, longest pectoral ray 3.1, and longest caudal ray 2.6.

The dentary of the larva has an enlarged tooth on each side of the symphysis, followed by a series of short, uniform conical teeth in 1 or 2 rows. The premaxillary is protractile and has 1 or 2 rows of short conical teeth which decrease in size posteriorly. There are no enlarged symphyseal teeth on the premaxillary. Vomerine and palatine teeth are absent. The only scales are 2 deeply embedded ossicles on the upper sides just behind the head. These also occur in adults and are probably vestiges of a lateral line which is not otherwise indicated. The anterior nostril is an oval opening, the posterior one an elongate slit.

Pigmentation of the larva consists of scattered large melanophores on the sides of the distended abdomen, on the breast, on the edge of the shoulder girdle beneath the operculum, and on the sides of the neck just behind the cranium. There is a row of small melanophores from the chin down the length of the isthmus, and also continuing into the mouth, across its floor to the velum posterior to the dentary. A single large melanophore occurs on the midline of the head over the frontal bone. The brain is visible through the otherwise unpigmented cranial roof, as are the stomach and other viscera through the translucent abdominal walls. In contrast to the adult (see below), the larva lacks a black peritoneum as well as black pigment in the stomach walls.

Counts made on the 4 fish are as follows (adults in parentheses): dorsal rays excluding vexillum 178 (175, 176); anal rays 177 (170, 171); pectoral rays 26–26 (26–26, 25–26, 25–26); caudal rays 6 (6, 6); branchiostegal rays 7 (7, 7, 7); gill rakers on first arch 9 (3, 3, 3). In the midtail region, the fin rays of the larva average 1.5 per vertebra.

The larval *Snyderidia* was not dissected, but some data on internal anatomy were obtained from the adults.

The adult stomach is large and remarkable in that it is composed of a thick muscular outer wall, a thin black middle layer, and a thick white mucosa, which is thrown into rugae when the stomach is empty. One wonders about the function of this black stomach pigment, especially since the parietal peritoneum is also black. McAllister (1960)

suggested that the black peritoneum of bathypelagic fishes prevents light from eaten (but still luminescent) prey from shining through the thin body wall, revealing the consumer's presence to a larger predator. If this is its function, there should be no need for additional screening in the stomach.

The intestine arises at the muscular pylorus located dorsally on the stomach. It has 3 flexures in its short length and contains a dense lining of papillae in its anterior third. Posteriorly, the papillae are lacking and the intestinal wall is thin. The wall thickens to form a rectum just before the anus. The rectum is prolapsed in all of my specimens, the protruding portion being black except in the larva. In life, this protruding black portion would be internal, and might then act to prevent light from shining from the anus.

The stomachs of all adults were empty, although the intestine of 1 contained a few unidentifiable crustacean appendages.

The entire dorsal surface of the brain, from the olfactory nerves to the spinal cord, is visible through the transparent skin and frontal bone of *Snyderidia*. The brain occupies less than half the cranial cavity, the remaining space being filled with a thin, clear liquid. There is no sign of a cartilaginous endosteum overlying the brain, as is sometimes the case in fishes with transparent cranial roofs. The brain's configuration is typically teleostean except that the olfactory bulbs are not contiguous with the telencephalon (they are borne on short pedicels) and the cerebellum has a raised anterior prominence.

A small window was cut in the frontal bone to facilitate examining the pineal region. The tiny pineal organ is digitiform and lacks a vesicular tip. It arches over the posterior telencephalon and touches the sparsely pigmented meninges which loosely envelop the brain. Its degree of development is disappointing in view of the transparency of the dorsal cranium, for according to Rasquin (1958), one might expect some elaboration of the pineal organ under such conditions. On the other hand, Holmgren (1958) has pointed out the possibility that most of the diencephalon is involved in light reception, and not just the pineal organ. An enlarged pineal apparatus would thus not necessarily be indicated.

Sex could be determined in only 1 specimen, a 208-mm female. The ovaries are fused to form a single elongate organ running dorsoventrally on the left side of the body cavity. Each ovary retains its own lumen, around which are arranged a multitude of egg-containing ceca. The eggs are tiny, spherical, and pink in this alizarin-stained fish.

Relationships

The presence of a vexillum in its larval stage is one reason for relating *Snyderidia* to the Carapidae. Other lines of evidence leading to this conclusion have been developed by Smith (1955) and Gosline (1960). Two additional anatomical features, the presence of predorsal bones and the structure of the caudal fin, have also been examined to determine family relationships. The following comparative material was examined: Ophidiidae, 2 specimens of *Rissola marginata* (DeKay), 91 and 189 mm SL; Brotulidae, 2 specimens of *Brotula multibarbata* Temminck and Schlegel, 48 and 134 mm SL; and Carapidae, 1 specimen of *Encheliophis gracilis* (Bleeker), 237 mm SL. Each was stained with alizarin and dissected.

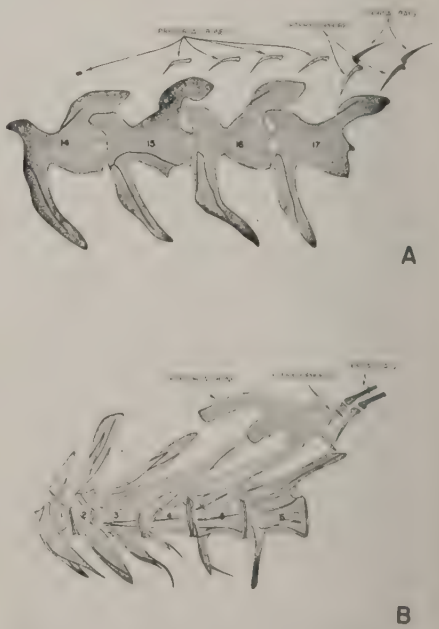

Fig. 2. Predorsal bones of A *Encheliophis gracilis* 237 mm SL, and B *Snyderidia canina* 212 mm SL.

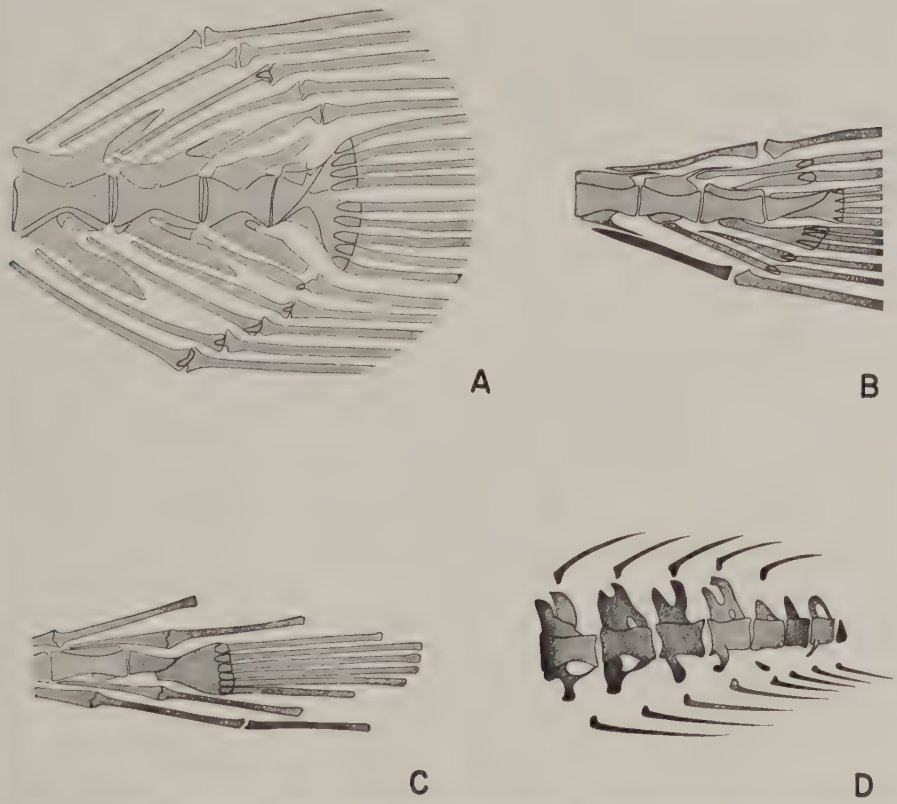

Fig. 3. Caudal structure of A *Rissola marginata* 91 mm SL, B *Brotula multibarbata* 48 mm SL, C *Snyderidia canina* 212 mm SL, and D *Encheliophis gracilis* 237 mm SL.

Smith and Bailey (1961) postulated that percoid ancestors lacked predorsal bones but subsequently acquired them through a backward shift of the dorsal fin. This shift left 1 or more pterygiophores without a fin ray to support, and the persistent basal segment of each such pterygiophore then became a predorsal bone. Within the Percoidea, some groups have tended toward an increasing number of predorsals, while others have tended to lose these bones.

In the ophidioid fishes, neither *Rissola marginata* nor *Brotula multibarbata* has predorsal bones. In *Rissola*, the basal pterygiophore of the first dorsal ray lies posterior to the neural spine of the seventh vertebra. The first ray is closely associated with the first pterygiophore, not with the second. In *Brotula*, the basal pterygiophore of the first dorsal ray lies above the neural spine of the second vertebra. The first ray is somewhat posterior to the first pterygiophore and appears to be more closely associated with the second pterygiophore than with the first.

Both *Encheliophis gracilis* and *Snyderidia canina* have predorsal bones, although there are great differences in structure between them. In *Encheliophis* (Fig. 2A), the first predorsal bone is rudimentary and lies over the fourteenth vertebra. The second through fifth predorsals occur above the fifteenth and sixteenth vertebrae, where they have the same configuration as the pterygiophores which follow them. In *Snyderidia* (Fig. 2B), there is only 1 predorsal, a large multirooted structure lying over the third, fourth, and fifth vertebrae, with a finger-like extension approaching the neural spine of the sixth vertebra. This complex predorsal bone probably represents the fusion of several former pterygiophores (or predorsals), for the orientation of its roots parallels that of the suc-

ceeding pterygiophores. Strictly speaking, it may be called a predorsal bone only in the adult of *Snyderidia*, as in the larva the vexillum overlies its posterior tip and is probably supported by it. A persistent vexillum base has been found in a late tenuis stage of the Carapidae (Strasburg 1961), but there is no trace of one in the 237-mm adult *Encheliophis* examined here.

The caudal osteology of representatives of 4 ophidioid families is shown in Fig. 3. At one extreme lies *Rissola*, in which there is a bilobed hypural plate and the vertebrae bear neural and hemal spines and zygapophyses. *Brotula* is less developed in that its hypural plate is a simple fan, without indication of lobes, and the broad hemal spine of the penultimate vertebra also bears caudal rays (there may be 2 such hemal spines on this vertebra according to Gosline 1953; perhaps the second develops with age). Perhaps this hemal spine should not be called a hypural, although functionally it contributes almost as much to the caudal base as does the hypural plate. The posterior vertebrae of *Brotula* are elongate and do not bear zygapophyses.

Snyderidia shows a great simplification of the caudal structure. The hypural is a simple lobeless fan which is not particularly well attached to the urostyle or aligned with the longitudinal axis of the vertebral column. In the stained larva, the hypural is not present, the space between the urostyle and the caudal rays being unossified and featureless. In all specimens of *Snyderidia*, the posterior vertebrae are elongate, rod-like, and lack processes for articulation with the pterygiophores.

Encheliophis has the most reduced caudal skeleton. Apparently, no true caudal fin ever forms in the Carapidae, and, in addition, the terminal vertebrae are lost during ontogenesis (Emery 1880). In the 237-mm fish shown in Fig. 3D, it would appear that there is a continuing loss of vertebral substance through attrition or resorption. Anterior to the region of loss there are normal vertebrae, the structure of which is more complex than in *Snyderidia* or *Brotula*.

There is obviously a wide range in size and complexity among the caudal fins of ophidioid fishes. The species selected show essentially the homocercal, diphycercal, and acaudate conditions. From a practical point of view it is doubtful whether the caudal fin contributes very much to the locomotory or balancing prowess of any of the species considered.

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A SUBMARINE FOR RESEARCH IN FISHERIES AND OCEANOGRAPHY

By

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Abstract

The Bureau of Commercial Fisheries Biological Laboratory in Honolulu is charged with exploring and developing the fishery resources of the central Pacific Ocean. As presently understood, these resources consist of several species of tuna and other large pelagic fishes. Attention has been focused on the tunas, especially on skipjack, a species not heavily exploited at present. Current research programs involve studies of tuna life history, behavior, racial structure, and environmental relations.

It has become increasingly apparent that neither the tuna resource nor the oceanic environment can be fully understood from observations made from surface vessels. A fishery/oceanography submarine has been proposed as a better platform for tuna research. The known behavior and distribution of tuna indicate that such a vehicle should have a 20-knot speed, a 1,000-foot operational depth, and a submerged endurance of 6 weeks. Provisions for direct viewing of fish, continuous environmental sampling, and quiet operations are also essential.

A feasibility/conceptual design study of the vessel shows it to be 163.5 feet in length, 23 feet in diameter, nuclear-powered, and manned by a crew of 24 plus 7 scientists. Innovations include an observation sphere, two research laboratories, several deep-sampling devices, and a unique motor arrangement.

INTRODUCTION

The Bureau of Commercial Fisheries Biological Laboratory in Honolulu conducts a multifaceted research program keyed to the exploration and development of the fishery resources of the central Pacific Ocean. As presently understood the principal resources are several species of tuna and some other large pelagic fishes. Attention has been focused on the tunas, especially on skipjack, a species not heavily exploited at present. The Laboratory's current research embraces the fields of oceanography, organic productivity, fishery biology, fish behavior, and genetics. Data for most programs are supplied by two surface ships.

Although a large store of knowledge has been acquired, it has become increasingly apparent that neither the tuna resource nor the oceanic environment can be fully understood from surface vessels alone. Ships are generally slow, noisy, unstable in terms of their use as platforms for delicate work, and, most important, they do not place the scientist in the environment he wishes to study. A fishery/oceanography submarine has been proposed as a better platform for tuna research. Such a vehicle

Reprinted from

OCEAN SCIENCE AND OCEAN ENGINEERING

Transactions of the Joint Conference,
Marine Technology Society and American Society of Limnology and Oceanography
Washington, D. C., June 1965

would be fast, quiet, stable, and totally immersed in the marine environment. By operating through a broad range of depths a submarine could place an observer in any undersea system he wished to examine.

RESEARCH APPLICATIONS

There are a number of research missions of great value to the Honolulu Laboratory which can be ideally undertaken by a submarine. In this category are studies on such oceanic features as thermoclines, fronts, currents, turbulence and waves, where precise control and the ability to hover or maneuver in three dimensions are needed to define the environment and to determine the relations between variables. A similar research area involves studies on ecology and ecological succession in water masses. A neutrally buoyant submarine can accompany a particular water mass, monitoring its changing physical and biological properties. A submarine, by being independent of weather, can also collect biological and oceanographic data from high latitudes in the winter, a time when major water masses are formed and when seasonal storms restrict the operation of most oceanographic research ships. When equipped with windows or television, a submarine is uniquely qualified to permit direct observations on fish, shrimp and other animals impossible to study from the surface. Its inherently quiet operation makes a submarine an ideal platform for studying biological sound, the effects of sound on animals, and the efficacy of various kinds of acoustic devices. A submarine is also well suited for evaluating the effectiveness of fishing gear such as nets, trawls, and lines, as well as the behavior of animals toward this equipment.

In addition to its ability to undertake these unique missions, a submarine offers other advantages over a surface ship. Its speed allows it to accomplish synoptic surveys in about half the time, and it can also record a variety of environmental data simultaneously and continuously. The latter feature provides the scientist with a fund of information impossible to obtain from ships, and permits him to undertake multivariate analyses. A submarine can operate in such a way as to isolate the effects of single environmental variables; for example, it is possible to study the distribution of plankton at a constant level of illumination. Delicate work such as sorting plankton by microscope and rearing larval fish can also be done on a stable, smooth-riding submarine. Most important, the scientist in a submarine is surrounded by the environment he wishes to study. His ability to make direct observations on this environment is invaluable.

RESEARCH SUBMARINE CONCEPT

Having developed the above philosophy on the utility of a fishery/oceanography submarine, the Bureau of Commercial Fisheries turned to Industry for an evaluation of the concept's engineering feasibility. Early in 1964 a contract was negotiated with Electric Boat Division of General Dynamics Corporation for a feasibility/conceptual design study of a research submarine. The known behavior and distribution of tuna required the proposed vehicle to have a submerged speed of 20 knots, operate at 1,000-foot depths, have a 25,000-mile range, undertake 30-to-90 day cruises and dives of 2-6 weeks duration, carry 7 scientists and elaborate instrumentation, be capable of quiet operations, and be highly maneuverable. The study was completed in January 1965, and a summary of it comprises the balance of this report.

The contractor found the proposed vehicle to be feasible in all respects, with performance in some areas exceeding the initial requirements. The vessel's characteristics and salient performance features are summarized below:

Hull material	HY80
Hull diameter (ft.)	23.0
Overall length (ft.)	163.5
Total shaft horsepower	3,240
Shaft horsepower per motor pod	810
Reactor power (Mw(th))	17.0
Normal surface displacement (tons)	1,265
Net submerged displacement (tons)	1,407
Stability and trim lead (tons)	37 (2.9%)
Margin lead (tons)	145 (11.5%)
Main ballast (tons)	142
Reserve buoyancy	11.2%
Maximum speed, submerged (kn.)	20
Maximum speed, surfaced (kn.)	11
Turning radius at slow speeds (ft.)	150
Forward laboratory space (cylindrical)	
Volume ($ft.^3$)	2,900
Floor area ($ft.^2$)	290
After laboratory space (cylindrical)	
Volume ($ft.^3$)	1,450
Floor area ($ft.^2$)	65
Operating depth (ft.)	1,000
Collapse depth (ft.)	1,500
Dive duration (weeks)	9

The vehicle is unique in several respects. Considering first the scientific equipment and arrangements, there is an 8-foot observation sphere in the bow, followed by the main scientific laboratory, 17 feet in length. At the stern is another laboratory, 24 feet long and 9 feet in diameter. The observation sphere has 5 plexiglass windows for direct observation of fauna, gear, the bottom, etc. The main scientific laboratory contains typical laboratory facilities for the examination of biological and oceanographic specimens and data, including microscopes, sinks, instruments, chemicals, racks, a library, and storage spaces. Among the apparatus and instruments providing information to this laboratory are a water sampler which delivers 15 simultaneous water samples; 2 hull-mounted instruments for recording temperature, salinity and depth; an instrument measuring salinity, temperature, oxygen and depth, and capable of being lowered on a 6,000-foot cable; a CTFM sonar; a photometer; a particle counter; 2 inverted echo sounders; hydrophones; a transponder-interrogator; a sound-velocity meter; a sound spectrograph; and 7 television cameras with their associated lights. Some of the data input is taped and fed to a computer in the laboratory's lower level. The stern laboratory's main piece of equipment is a tube from which trawls, plankton nets, fishing lines, bottom samplers and other instruments can be launched while submerged. This tube can also receive water pumped from the outside by four pumps, each with a capacity of 2,250 gallons/minute. Plankton can be filtered from this water by placing a collecting net in the outboard end of the tube.

The stern laboratory could not exist if a single propulsive screw were employed on this submarine. The stern configuration was selected to free the central area for a laboratory and at the same time to provide for a high degree of maneuverability. An 810-horsepower, tractor-type, oil-filled brushless motor is mounted on each of the horizontal and vertical stabilizers at the stern. Only electrical leads go to these motors, thereby eliminating shaft-seal problems. The redundancy in having four motors also increases safety.

Lack of space prevents describing all of the submarine's features. Some of the salient items which should be mentioned include the pressurized water reactor, the battery for quiet operation, and the diesel engine for emergency use. There is a decompression chamber, and access for divers to depths of 100 feet. The ballasting system has a hovering mode involving automatic controls. Navigational equipment includes radar, radio, loran, fathometers, sonar, a periscope, and probably an inertial navigation device. The total crew is 24, exclusive of 7 scientists. The estimated design and construction time of the vessel is 4-1/2 years.

BENEFITS

This submarine will benefit the American public in many ways. Its most obvious contributions will be the acquisition of knowledge vital to our understanding and control of the sea's fishery resources, the development of improved methods of locating and harvesting these riches, and the discovery of marine wealth which is presently untouched. The information obtained will also be invaluable to the sciences of meteorology, oceanography and ocean engineering. The phenomena embraced by these disciplines have far-reaching effects on the American people in terms of shipping, marine construction of all kinds, long-range weather forecasting, recreation, and waste disposal. The data are also broadly applicable to our national defense and to our attempts to colonize the sea floor. The vessel has the immeasurable advantage of permitting man to explore and develop an alien environment directly and on his own terms. It is this feature which promises an order of magnitude increase in reward from a storehouse which is rich beyond comprehension.

Reprinted from Biological Bulletin, Vol. 129, No. 2, 371–387, October, 1965
Printed in U. S. A.

A MICROSPORIDIAN INFECTION OF THE DIGESTIVE TRACT OF THE WINTER FLOUNDER, PSEUDOPLEURONECTES AMERICANUS [1]

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Linton (1901) reported sporozoan infections in two small winter flounders, *Pseudopleuronectes americanus*, taken from Katama Bay, Martha's Vineyard, and examined at Woods Hole on August 28, 1900. His account, although brief, is adequate for recognition of the parasite and reads (p. 487), "The walls of the intestine of one throughout almost the entire length and of the other for a short distance were completely covered with sporocysts. The cysts were irregular where crowded together; where not crowded together, which was in but few places, they were elliptical or spherical, of various sizes, but comparatively few reaching 1 mm. in diameter and none much exceeding that. Spores oblong-ovate about 0.003 mm. in length and 0.0015 mm. in diameter. Intestine where affected was chalky-white in color." The accompanying figure shows a "Piece of intestine of *Pseudopleuronectes americanus*, serous coat covered with cysts due to sporosperms (*sic*)." There was no attempt at identification of the parasite, but Linton recognized that it was distinct from another, reported in the same publication (pp. 438 and 439), found in the muscles of the back and sides of the herring, *Clupea harengus*, and the alewife, *Pomolobus pseudoharengus*.

The latter species was identified as a myxosporidian and almost one-half of the young fishes were infected. Tyzzer (1900) reported the discovery and prevalence of this infection in young *P. pseudoharengus;* Auerbach (1910) assigned the species to the genus *Chloromyxum* Mingazzini, 1890; and Hahn (1917) proposed the specific name, *Chloromyxum clupeidae*. The allocation to *Chloromyxum* was based on the spore, which has a quadrilateral apical end and bears four polar capsules. Kudo (1920, p. 94) examined the slides prepared by Tyzzer, and others made from various species of fishes, and reported the infection in *Clupea harengus, Pomolobus pseudoharengus, P. aestivalis, P. mediocris, Brevoortia tyrannus, Stenotomus chrysops,* and *Tautogolabrus adspersus*, taken at Woods Hole. The parasites from the muscles of these fishes were regarded as specifically identical and referred to *Chloromyxum clupeidae* Hahn, 1917.

A third sporozoan was reported by Linton (1901; p. 455) from the liver of the butterfish, *Poronotus triacanthus* (syn. *Rhombus triacanthus*). The cyst was white and globular, about 1.5 mm. in diameter; when compressed it liberated immense numbers of spores, often aggregated in globular or oblong clusters, as large as 0.02 mm. in diameter. The spores were short and thick, with bluntly rounded ends, about 0.0025 mm. in length and a little less than that in breadth and thickness.

[1] This investigation was supported in part by NSF-GB-3606, Continuation of G23561.

The parasite is obviously a microsporidian and Woodcock (1904; p. 54) regarded it as a species of *Pleistophora*.

A fourth sporozoan was observed by Linton (1901; p. 433): an enormous number of small elliptical bodies, 14 by 6 microns, were found in the intestinal contents of a sting-ray, *Dasyatis centroura*. Since the spores were in the lumen of the gut, it is apparent that they were ingested in food and were parasitic in some animal other than the ray.

The parasites reported by Linton from the wall of the digestive tract of *P. americanus* are similar to and possibly identical with others reported about the same time from flat-fishes of Europe. Hagenmüller (1899) observed the infection in at least one-half ("18 fois sur 30") of the small fishes, *Flexus passer* Moreau (= *Pleuronectes passer*) from littoral pools in the area of Endoûme, Bouches-du-Rhône, France. The parasite was named *Nosema stephani* in honor of M. Pierre Stephan, who first found the cysts and called them to the attention of the author. He wrote (p. 837, "Cette Myxosporidie appartient au genre *Glugea* Thélohan, aujourd'hui *Nosema;* elle infeste, sous forme d'infiltration diffuse ou de kystes, les parois du tube digestif . . . L'infiltration diffuse représente plus particulièrement un mode de pullulation endogène, tandis que les kystes assurent la dissémination du parasite à l'extérieur. Kystes et amas d'infiltration s'observent depuis la partie supérieure de l'oesophage jusqu' à l'extrémeté du rectum, logés dans les tissus ou simplement recouverts par le péritoine. Il n'existe ni amas ni kystes dans le parenchyme d'aucun organe, rein, rate, foie, coeur, etc. Cependant, sous le péritoine à la surface du foie et dans les replis péritonéaux où cheminent des vaisseaux, les kystes sont assez nombreux; j'en ai trouvé jusque sur le conduit cholédoque près de son abouchement avec l'intestin. Dans la paroi intestinale, les kystes siègent dans les couches musculaires et surtout dans la couche conjonctive. J'en ai vu jusque dans la charpente conjonctive des replis de la muqueuse et des villosités, mais jamais, non plus que d'infiltration diffuse, dans la couche épithéliale de l'intestin.

"Ces kystes apparaissent à l'oeil nu comme de petits grains d'un blanc de lait, ovoïdes ou plus rarement sphériques, ne dépassant guère 1 mm. en diamètre, n'atteignant même pour la plupart que quelques dixièmes de millimètre, ou moins encore." Hagenmüller discussed the formation of the cyst and concluded that the membranous wall is produced by the host as a reaction to invasion by the parasite.

A similar and presumably identical species was reported by Johnstone (1901) from the plaice, *Pleuronectes platessa*, taken in the Irish Sea along the coast of Lancashire. The author recognized the parasite as a protozoan, probably a sporozoan, but further identification was not attempted. The infection was limited to the digestive tract and the intestine, from the pylorus to the anus, was thickened and superficially looked like a ripe ovary. The external surface was studded with small, round, white, opaque bodies; the internal surface was disposed in irregular, longitudinal folds, covered with projecting, round white bodies; the lumen was reduced and the mucosa often lost; and the wall measured 3 to 4 mm. in thickness. The cysts were about 0.60 mm. in diameter, with a capsule composed of an outer cuticular and an inner fibrous layer. The spores were oval with a maximum length of 0.005 mm. Figures portrayed the gross appearance of the intestine, the structure of the wall, and the form of the spores.

Woodcock (1904) described a second infection in the digestive tract of the plaice, *P. platessa,* taken near Plymouth, England, and discussed the Myxosporidia in flatfishes. For him, the Myxosporidia Bütschli, 1881 were "characterized (a) by the fact that reproduction by spores goes on throughout the growing or 'trophic' period, and (b) by the complicated process of spore-formation and the nature of the spores." The group was, thus, the equivalent of the Neosporidia Schaudinn, 1900 and the Cnidosporidia Doflein, 1901, and included the Microsporidia Balbiana, 1882. Woodcock reviewed the papers by Hagenmüller, Linton, and Johnstone; he noted that the infection reported by Johnstone was a "ripe, well-matured one," extensively distributed, whereas the infection he studied was only a slight and limited one, from a fish that superficially was quite healthy in appearance. In this specimen, the gut showed little oval patches, 1.00 mm. in diameter, usually projecting slightly on the outer, coelomic side together with other small pyriform appendages, 1.50 to 2.00 mm. in length, attached to the gut by the narrow end. These enlargements were all on the side of the gut to which the mesentery was attached, and in which the blood vessels ran. The functional activity of the intestine was not impaired; the mucosa was intact and normal in appearance. Woodcock compared sections made from the lightly infected intestine with others made from material sent by Dr. Johnstone. He discussed endogenous multiplication ("multiplicative reproduction" of Doflein) in young forms, the spread of the infection into neighboring tissue by diffuse infiltration and the formation of cysts and pseudocysts. He stated (p. 57), "Quite probably 'multiplicative reproduction' is, here, simply a separation of the pansporoblast rudiments, as daughter individuals. Indeed the whole nature of diffuse infiltration in *Glugea* seems to me to support this idea. There is no question of the individual parasites attaining size, still less of any continuity of a protoplasmic mass ramifying in and between host's tissue-cells. It is far rather a cell-infection, visible, when ripe, as separate clumps of spores, each formed from, and representing, one pansporoblast, and either still surrounded by a hypertrophied host-cell, or else free, but only owing to the latter's breakdown." The infections reported by Hagenmüller, Linton and Johnstone were referred to the same species, here designated as *Glugea stephani* (Hagenmüller, 1899) Woodcock, 1904.

Stempell (1904) studied the development of *Nosema anomala* Moniez, 1887, a species from the connective tissue in subcutaneous loci and in the gut-wall, liver, and gonads of the fresh-water stickleback, *Gasterosteus aculeatus.* This species had been transferred by Gurley (1893) to the genus, *Glugea* Thélohan, 1891. Stempell noted that recent investigations had disclosed a series of protozoan species in which the life-cycles consisted of a limited period of vegetative, asexual multiplication, after which different, *"gartete"* forms appear, whose further multiplication is conditional on the conjugation or copulation of two individuals. After citing essentials of these investigations he stated (p. 31), "Bedenkt mann dagegen, dass die allgemeiner Grundzüge der Entwicklung, soweit sie sich feststellen liessen, in allen Fällen dieselben sind, so darf man wohl mit Recht schliessen, dass sämtliche beschriebenen Parasitenformen der Spezies *Nosema anomalum* Monz. angehoren. In der Tat, ein treffender Name für eine so variable Spezies!" Accordingly, he returned the species, *anomala,* to the genus *Nosema.* In this species he reported growth of the protoplasmic masses with rapid, asexual multiplication of

nuclei, followed by the differentiation of sporonts, the admitted progenitors of the sexual generation. His account reads (p. 33), "Wir sehen, wie in der enzystierten Parasitenmasse zunächst ein Wachstum des Protoplasmas und eine starke Vermehrung der Kerne auf rein ungeschlechtlichem Wege erfolgt, wie sich aber schon sehr bald aus dieser vegetativen Parasitenmasse die als Vorfahren der Geschlechtsgeneration aufzufassenden Sporonten differenzieren. Nur dadurch unterscheiden sich die vorliegenden Microsporidien und so viele phänozyste Myxosporidien von der Mehrzahl des anderen Sporozoen, dass diese Geschlechtgeneration durch endogene Knospung im Körper der vegetativen Individuen entsteht."

Weissenberg (1911) reported that about 2% of the smelt, *Osmerus eperlanus*, taken from sources near Berlin and from inlets of the Baltic Sea, were infected with a microsporidian parasite, similar to but distinct from *Glugea anomala*, which he described as a new species, *Glugea hertwigi*. He observed no difference in the infections of fishes from fresh and salt water. In a second paper, Weissenberg (1913) reviewed the work of Stempell (1904) and other authors on microsporidian species and reported on the life-cycles of *G. anomala* and *G. hertwigi*. Since the time of Pasteur it has been known that certain microsporidians invade the ovary and penetrate the ova, with hereditary transmission of infection. Stempell described such infected ova, but Weissenberg (1913) declared the evidence was not convincing. To test the matter, he raised sticklebacks, *Gasterosteus aculeatus*, from eggs. When the yolk-sacs were resorbed he fed small copepoda and daphnids but the fishes did not grow. Fine emulsions of spores were added to the water, but no infection resulted. With other fishes raised in aquaria but fed plankton with an abundance of plant and animal food, growth was good and two young sticklebacks daily were fed plankton mixed with an emulsion of spores. Three weeks after the beginning of the experiment, one of the fishes had a *Glugea*-cyst, 300 microns in diameter, on the wall of the throat. This result demonstrates that a fish raised in the laboratory became infected and provides information on the rate of cyst formation. Weissenberg concluded (p. 157), "Wenngleich die oben dargelegten Befunde bezüglich der Entwicklungsprozesse von *Glugea anomala* in zahlreichen Punkten von den Ergebnissen der Voruntersucher abweichen, so gelange ich doch zu der gleichen Gesamtauffassung wie die älteren Autoren, insbesonder Stempell. Auch nach meinen Befunden kommt *Glugea* ein grosser eigener Plasmakörper mit zahlreichen vegetativen Kernen zu. Die ganze Cyste gehört zum Protozoon. Wirtszellen oder hypertrophische Wirtskerne sind am Cystenaufbau nicht beteiligt." In a subsequent paper, Weissenberg (1921) discussed the problem whether or not the large Plasmakörper, with its large vesicular nuclei, is derived from host tissue or is of protozoan origin. After presenting new evidence he concluded (p. 420), "An der Wirtsgewebsableitung des Plasmakörpers und der bläschenförmigen Kerne der *Glugea*-Cysten kann nun nicht mehr gezweifelt werden. Aufgabe künftiger Forschung wird es sein, die Art der phagocytenartigen verstreut im Bindegewebe auftretenden Fischzellen, die somit den Mutterboden für die *Glugea*-Cysten abgeben, genauer zu eruieren."

Meanwhile, Mavor (1915) reported that about 50% of the *Pseudopleuronectes americanus* examined in the summer and autumn of 1910 at Woods Hole, Mass., were infected with *Glugea stephani*. He also found *Osmerus mordax* at Woods Hole frequently infected with a microsporidian, apparently *G. stephani*. These find-

ings are in marked contrast to others made in the summer of 1912, when no infections were found on examination of 82 *P. americanus and* 22 *O. mordax* taken in the region of St. Andrews, New Brunswick. Kudo (1924) suspected that the parasite of *O. mordax* was *Glugea hertwigi.*

Schrader (1921) found 28% to 53% of the smelts, *O. mordax* from lakes in New Hampshire, and 1.5% to 16% of those from the coast of Maine were infected with a species which he identified as *O. hertwigi* Weissenberg, 1911. The intestine was the primary seat of infection although cysts were present in the liver and gonads. The cysts ranged in size from microscopic to 3 mm. in diameter, but were similar in size in each fish. The highest incidence of infection was in immature fishes, about 10 cm. long; adult fishes were rarely parasitized and Schrader predicated that the majority of infected fish die while immature. Unlike *G. anomala, G. hertwigi* was regarded as specific for smelts since other fishes in the same area were not infected. Furthermore, connective tissue and muscles were not infected, which apparently served to distinguish *G. hertwigi* from *G. anomala.*

Reichenow (1929) described *Glugea stephani* from infections of *Pleuronectes limanda* at Helgoland. He found white cysts, 0.5 mm. in diameter, in the submucosa of the intestine and reported (p. 1099), "Die Parasiten bilden zuerst Infektionsherde in der Darmwand, die von Hagenmuller und Woodcock als Zustand diffuser Infiltration (vgl. S. 1046) bezeichnet werden. Die Parasiten haben jedoch keinen interzellulären Sitz, vielmehr befallen sie im Laufe ihrer Vermehrung zahllose benachbarte Zellen (entweder Bindegewebszellen oder vielleicht Leukocyten, die sich an der Infektionsstelle ansammeln). Um den ganzen Herd herum bildet sich eine dicke Bindegewebskapsel, und so entstehen die Cysten, deren Inhalt also in diesem Falle nicht durch eine einzige Riesenzelle, sondern durch viele infizierte Zellen dargestellt wird. Die fertig ausgebildeten Cysten findet man hauptsächlich von ungeheuren Sporenmassen erfüllt, zwischen denen verstreut Zell- und Kernreste vorkommen. Eine paarige Anlage der Sporen, welche die Stellung dieser Art zu der Gattung *Glugea* begründen würde, ist von keinem der Untersucher beschrieben worden. Ich habe in dem von mir beobachteten Falle eher den Eindruck gewonnen, dass die Sporen einzeln entstehen, so dass die Art also zu *Nosema* zu rechnen wäre. Doch wird sich dies erst bei Beobachtung früherer Infektionsstadien, die übersichtlichere Bilder geben, entscheiden lassen. In meinem Falle, in dem die Cysten dicht gedränkt in der Darmwand sassen, war die Schleimhaut auf weite Strecken völlig abgestossen; es ist daher zu vermuten, dass die Fische an starken Infektionen zugrunde gehen."

Recent accounts have added little information on microsporidian infections of fishes. Bond (1938) identified cysts found in sections of the stomach of *Fundulus heteroclitus* taken in Chesapeake Bay as *G. hertwigi,* but the determination may not be correct. Fantham *et al.* (1941) described an infection in the hindgut of a specimen of *O. mordax* taken from Lake Edward, Quebec, and listed the parasite as *G. hertwigi* var. *canadensis.* Also, they reported *G. stephani* in the submucosa of the intestine of *P. americanus* and *Limanda ferruginea,* taken near Halifax, Nova Scotia; *L. ferruginea* was recognized as a new host of the parasite. Haley (1952) described a severe epidemic of microsporidiosis in *O. mordax* in Loon Pond, Gilmanton, New Hampshire, and 16 of 20 *O. mordax* from the Oyster River taken at

Durham, N. H., were infected by the same species, which he identified as *G. hertwigi.*

The Microsporidia are chiefly parasites of invertebrates, especially crustaceans and insects. The classification of the Microsporidia or Microspirida is based primarily upon the form and structure of the spores and to a lesser degree upon differences in the details of sporogenesis. The parasites of *P. americanus* belong to the family Nosematidae, characterized by small, oval or ovate spores, each with one polar filament. The genera are distinguished by the number of spores that are produced by each sporont. According to Poisson (1953), in *Nosema* each sporont develops into a sporoblast and produces a single spore; in other genera the numbers of spores produced are: *Glugea* Thélohan, 1891 and *Pérezia* Léger et Duboscq, 1909, two spores; in *Gurleya* Doflein, 1898 and *Pyrotheca* Hesse, 1935, four sporoblasts and four spores; but in *Stempellia* Léger et Hesse, 1910, the numbers of spores produced are: *Glugea* Thélohan, 1891 and *Pérezia* Léger et Duboscq, number varies from 8 to 32; and in *Plistophora* Gurley, 1893, each sporont (pansporoblast) produces more than 16 spores. It is generally believed that the microsporidia are narrowly host-specific. According to Poisson (1953) some 40 species in the genera *Plistophora, Glugea,* and *Nosema* occur in fishes and one species, *Glugea danilewsky*, occurs in the muscles and connective tissue of *Rana fusca, Emys orbicularis, Natrix natrix* and other hosts. If this determination is correct, the distribution of *G. danilewsky* belies the opinion that species of *Glugea* are host-specific.

The life-history of the Microsporidia, as conceived by Debaisieux (1928), comprises two distinct phases: a multiplicative stage, schizogony, beginning with the liberation of the uninucleate or binucleate sporoplasm or planont from the spore and its entry into a host-cell, and sporogony, a spore-forming stage, in which sporonts produce sporoblasts that give rise to resistant spores, the infective agents that serve for dispersal of the parasite and the infection of new hosts. According to Kudo (1924, p. 34), "No intermediate host animals have up to date been found for Microsporidia. The infection of a new host animal takes place when the latter ingests spores of a specific microsporidian capable of germinating in its gut." A similar statement was made by Dogiel, Petrushevski and Polyanski (1961) but no reference to experimental evidence was cited.

It is generally agreed that the life-cycle of the microsporidian involves sexual phenomena but there is wide disagreement concerning the location in the cycle where meiosis and syngamy occur. Meiotic phenomena have never been observed in the Microsporidia and syngamy has been reported by autogamy of nuclei in the sporoplasm before or after release from the spore, and also by nuclear fusion preceding sporont formation. Writing on sexual phenomena in Protozoa, Hall (1953, p. 80) stated, "A reduction of the chromosomes to the haploid number may occur in gametogenesis (*gametic meiosis*), in an early division of the zygote (*zygotic meiosis*), or in one of the pregamic divisions in conjugation (*conjugated meiosis*). The type of meiosis varies in different Protozoa. Available data indicate that the Heliozoida, Foraminifera, Cnidosporidia, and Ciliophora are diploid throughout most of the life-cycle." An opposite opinion was stated by Cheissin and Poljansky (1963, p. 343), "In the life-cycles of the Sporozoa the alternation of sexual process and sporogony or that of sexual process, sporogony and repeated asexual multipli-

cation by means of schizogony occurs. All the developmental stages but zygote are haploid ones because the meiosis usually appears during the process of sporogony followed by formation of sporozoites." The statement by the Russian authors apparently is based on the situation in the malarial parasites, but the Microsporidia are distinct from the Haemosporidia and the life-cycles may be quite different. Indeed, Kudo (1944, p. 50) reporting on the life-cycle of *Nosema notabilis* Kudo, 1939, stated, "Schizogony is by binary fission. No sexual process has been observed in the development of *Nosema notabilis*."

The small size of the amoeboid stages and of the spores, usually less than 4 microns in length, together with the inability to obtain early stages by controlled experimental infections of fishes, has made it impossible to describe the developmental cycle of these microsporidian species with assurance. The time and place of chromosome-reduction in meiosis and of syngamy are controversial. Cells with two nuclei may represent a stage before fusion of gametes or the first division of a zygote. Specific distinctions are often precarious and even generic diagnoses are unsatisfactory. In his monographic treatise, Poisson (1953) stated (p. 1043), "Mais bien des espèces de Microsporidies sont insuffisamment étudiées; trop d'espèces ont été décrites comme nouvelles parce qu'elles étaient trouvées dans des hôtes nouveaux. D'après Steinhaus et Hughes par example, *Nosema destructor* S. et H, a été observée chez au moins 10 espèces d'Insectes apparentant à trois groupes différents: la chenille de *Gnorimoschema operculella* (Zeller) (Lépidoptère), des Hyménoptères, des Névroptéroides. Il est donc des Microsporidies qui ne manifestent qu'une spécificité toute relative. D'autre part, les caractères distinctifs utilisés pour séparer les espèces, et même les genres, n'offrent peut-être toujours la précision désirable et certains genres, tels les genres *Nosema, Plistophora, Glugea, Perezia,* devront être revisés."

Microsporidian infections of *Pseudopleuronectes americanus* have long been known by members of the staffs of the New York Aquarium and the New York State Conservation Department, but precise and detailed records of incidence and intensity are not available. Dr. Ross F. Nigrelli, at the Aquarium of the New York Zoological Society, has observed the frequent occurrence of the parasite in fishes of the New York area and Mr. John C. Poole of the Conservation Department reports that the infection has a "spotty" distribution, *e.g.,* in one year over 25% of the young of that year taken in Shinnecock Bay were infected and no infection was found in the same location the following year.

Materials and Methods

The present investigation was begun in the summer of 1961 and has been conducted more or less continuously since that time. Over 1000 fishes, *P. americanus*, taken from different locations in New England, have been inspected for microsporidian infection. Data have been compiled (Tables I–VI) on the number of fishes examined, the time of year and area where they were caught, their size, sex, and the incidence and intensity of infection. Fishes taken on Georges Bank, off Yarmouth, Nova Scotia, were caught on the August, 1963, cruise and those from Nantucket shoals on the April, 1964, cruise of the Albatross IV. Records denote the organs involved and the extent of infection. Winter flounder are present from April to November in Woods Hole harbor. The stomachs and intestines of 751

TABLE I

Incidence of microsporidian infection in winter flounder from Woods Hole Harbor in 1962

Month	Number examined	Number infected	Per cent infection
April	80	3	3.4
May	67	2	2.3
June	86	1	1.2
July	102	7	6.9
August	156	6	3.8
September	86	0	0.0
October	125	3	2.4
November	49	4	8.2
Total	751	26	3.5

fishes were removed and preserved for food analysis, and patent sporozoan infections were noted. Very light infections may have been missed, so the recorded intensity is minimal. Analysis of the stomach-contents was made to determine the kinds and amounts of food ingested. In November, 1964, about 300 young fishes that measured from 40 to 110 mm. in length were taken in Lake Tashmoo, Martha's Vineyard, where the infection-rate was known to be high. Eighty-five of these fishes, which died at the time of collecting or a few hours later, were examined and the results are given in Table VI. Heavy infections included those where the infil-

TABLE II

Length-distribution of microsporidian-infected winter flounder compared with that of all winter flounder examined, in Woods Hole Harbor during 1962

Length (cm.)	Number of fish		Length (cm.)	Number of fish	
	Total	Infected		Total	Infected
12	1		28	64	6
13	1		29	70	
14	1		30	66	2
15	6		31	70	1
16	3		32	66	1
17	4		33	48	2
18	7	1	34	45	1
19	11	1	35	33	2
20	11		36	20	
21	7		37	16	
22	15		38	6	1
23	19	2	39	6	
24	18		40	1	
25	33	2	41	2	
26	48	2	42	2	
27	51	2			
				751	26

TABLE III

Mean weights of infected and non-infected winter flounder from Woods Hole Harbor in 1962

Mean length cm.	Infected		Non-infected	
	Number	Mean weight	Number	Mean weight
July–August				
males				
23	2	193	5	211
30	2	366	9	351
33	1	443	7	439
34	1	402	4	513
females				
18	1	76	—	—
23	1	150	3	165
27	1	232	6	272
28	4	278	10	293
October–November				
males				
19	1	70	1	64
26	2	194	6	223
females				
28	1	280	9	270
31	1	404	9	368
35	1	541	8	551
38	1	652	3	774

tration was massive and the gut was partly or largely destroyed; light infections included those with from one to 20 cysts in the wall of the intestine. By the time that cysts are formed the infection is already well established.

In Table VI, the winter flounders less than 100 mm. in total length were of the 1964 year class, *i.e.*, less than a year old. Those of 100 mm. or more in length probably were of the 1963 year class, but final age-determination was not made.

Since the microsporidiosis is located primarily in the intestine, and the infective agent was presumably taken in with food, the stomach-contents of 751 fishes from

TABLE IV

Amount of food in stomachs of infected and non-infected winter flounder from Woods Hole Harbor in July–August, 1962

Month	Infected			Non-infected		
	Number	Mean length cm.	Food grams	Number	Mean length cm.	Food grams
July	7	28	1.25	102	30	2.19
August	6	26	1.02	156	27	0.82

TABLE V

Incidence of microsporidian infection in winter flounder from different New England fishing grounds

Location	Georges Bank		Off Yarmouth, Nova Scotia		Nantucket Shoals		Off Plymouth, Mass.	
Length cm.	Total number	Number infected	Total number	Number infected	Total number	Number infected	Total number	Number infected
11–15	1	0	0	0	0	0	0	0
16–20	1	0	1	1	0	0	0	0
21–25	0	0	0	0	16	1	1	0
26–30	1	0	0	0	25	1	0	0
31–35	6	0	2	0	53	11	12	1
36–40	6	0	3	0	23	7	5	2
41–45	16	0	2	0	8	1	1	0
46–50	2	0	0	0	1	0	0	0
51–55	3	0	0	0	0	0	0	0
56–60	1	0	0	0	0	0	0	0
61–65	1	0	0	0	0	0	0	0
Total	38	0	8	1	126	21	19	3
Per cent infected	0		1.2		16.7		15.8	

Woods Hole harbor have been examined in an attempt to discern the source or sources of the infective agent or agents. Also, since Microsporidia are presumed to be one-host parasites, microsporidian cysts from winter flounder gut-wall embedded

TABLE VI

Incidence of microsporidian infection in small winter flounder from Lake Tashmoo, Martha's Vineyard

Length (mm.)	Degree of infection		
	Heavy	Light	None
41– 45	2	0	0
46– 50	4	0	1
51– 55	6	1	1
56– 60	6	3	3
61– 65	2	3	4
66– 70	0	2	7
71– 75	1	6	8
76– 80	1	2	4
81– 85	0	2	4
86– 90	1	4	1
91– 95	0	0	2
96–100	0	0	0
101–105	0	0	2
106–110	0	0	2
Total	23	23	39

Per cent infected, 54.1.

in pieces of clam, *Mercenaria mercenaria,* have been fed to other winter flounder kept in aquaria in attempts to induce experimental infections. Cysts were fed to two fish in the summer of 1962. They were examined six weeks later and there was no evidence of infection. Five fish were fed cysts in November, 1964. Three were examined in April, 1965, and the other two were autopsied in June, 1965. No infection resulted from these experiments. It appears that direct infection does not occur, that either the sporoplasms do not emerge from the spores or they fail to invade the intestinal epithelium.

Tissues from natural infections were fixed in different fluids, cut in serial sections at 5 and 10 microns in thickness, and stained for particular effects. Haematoxylin and erythrosin were used for general purposes and routine pathological staining. Heidenhain's iron technique was employed on thin sections for cytological details and azan trichrome for special histology.

Results

The incidence of infection in 751 fishes taken in the Woods Hole harbor and examined each month, April through November, 1962, and data on the size and sex of the fishes are presented in Tables I–III. There was no apparent effect of seasonal or sexual differences. Table IV records the amount of food in the stomachs of infected and non-infected fishes of comparable sizes taken from Woods Hole harbor in July and August, 1962. There was no obvious relationship between infection and amount of food in the stomach. Stomach-contents of 386 fishes collected in weekly samples in September, October, and November, 1961, consisted by weight of algae, 42%; mollusks, 25%; polychaetes, 24%; crustaceans, 5%; and other (mostly unidentified), 4%. The results of analyses made in 1962 are similar, with less algae eaten in the spring and summer. No fish were found in any of the flounders examined, thus confirming the statements by Bean (1903), Breder (1929) and Bigelow and Schroeder (1953) that young flounders feed exclusively on algae and invertebrates, chiefly crustaceans and polychaete annelids. The account of Bigelow and Schroeder is very complete and includes the findings of Breder and Linton as well as their own observations. It is generally agreed that the small mouths of these flounders preclude the ingestion of fishes as food, and it appears certain that fish are of no significance in the diet of *P. americanus* in the Woods Hole area.

The incidence of infection in winter flounder of different sizes taken from different coastal areas and from Georges Bank, which is offshore, is presented in Table V. Although the number of fishes from Georges Bank is small, the absence of infection there may be significant. There is evidence that Georges Bank winter flounder are geographically isolated from those on inshore grounds and that they have no contact with the shore at any time during their lives. Results from the release on inshore grounds of over 10,000 tagged winter flounder indicate that only one was re-caught on Georges Bank (Perlmutter, 1947; Bigelow and Schroeder, 1953). Perlmutter also reported that winter flounder from Georges Bank have more fin rays than those from inshore grounds north and south of Cape Cod. Winter flounder from inshore subpopulations, on the other hand, are closely associated with the shore, spending their first year in estuaries and bays where much of the spawning occurs, and where infection may take place.

The data from the small fishes taken in November, 1964, at Martha's Vineyard (Table VI) are particularly interesting. In addition to the information presented in the table, 49 individuals in the same size-range died in the period November 20 to December 7, 1964. Nineteen of these fishes, mostly 65 to 85 mm. in length, were infected, with an incidence of 38.8%. Seven of the infections were heavy; 12 of them were light. Fifteen of the remaining fishes were killed March 12, 1965, and 8 of them, *i.e.*, 53.3%, were infected. Three of these infections were heavy; five were light. Inspection of the data from the 149 fishes examined shows that infection was greatest in small fishes. Almost all of the heavily infected ones were less than 80 mm. in length and some of them were less than 50 mm. in length. Since development of such massive infections must take some time, it is apparent that infection occurred very early in life, when the food consisted of small invertebrates. Comparison of the findings recorded in Tables II and VI, indicates strongly that fishes heavily infected during the first year of life do not survive into their second year.

The site of infection is primarily the wall of the intestine and pyloric ceca, but in moderate and heavy infections, other structures adjacent to or in contact with the gut may be involved. These include the bile-duct, liver, mesenterial lymph-nodes and the ovary. The infections observed were already well advanced and were manifest by cysts (Figs. 4, 5) embedded in the connective tissue of the organs affected. In larger fishes, most of the infections were light and apparently did not seriously affect the hosts. In light infections, the cysts were usually on the external wall of the intestine, but in heavy ones, the gut wall was largely supplanted by layers of cysts. In such instances the intestine had a chalk-white, pebbled appearance and the wall was rigid, thickened and hard. Photographs of intact normal and parasitized digestive tracts and of sections of the intestine and cecum of infected fishes portray the effects of massive infection. Figure 1 is of a normal digestive tract. In the specimen shown in Figure 2, the anterior end of the digestive tract is the principal site of infection, whereas in Figure 3, it is the rectal end of the specimen that is most heavily parasitized. Figure 4 is a photograph of a cross-section of the intestine shown in Figure 2, and Figure 5 is a photograph of a cross-section of one of the pyloric ceca taken from the specimen shown in Figure 2. The epithelium of the intestine in Figure 4 is denuded and the lumen of the cecum (Fig. 5) is almost occluded.

The cysts are spherical to oval unless deformed by pressure. They measure 0.6 to 1.0 mm. in diameter and the wall (Figs. 6, 7) is composed of laminated layers that have the structural appearance and staining reactions of the connective tissue of the host. In addition to those in the cysts, there are masses or strands of spores scattered about in the tissue of the gut wall, often associated with or paralleling blood vessels. The material at present available for study consists of relatively mature infections and the multiplicative phases have largely been completed. Rarely, near the wall of a cyst or in the intercystal areas there is a cell, which may be a pansporoblast, which contains a large number of bodies that color deeply with nuclear stains. Whether or not these structures are the nuclei of sporoblasts could not be determined. Below the connective capsule of the cyst there is often a narrow layer of stainable material, termed endoplasm by Woodcock, which contains large oval, apparently pycnotic, nuclei with fragmented chromatin and distinct nu-

cleoli. Their presence suggests that the cyst is formed around a number of host-cells, whose cytoplasm has been consumed and whose nuclei persist below the wall of the cyst. The spores are oval to ovate, and when fixed and stained measure about 4 by 2.5 microns. Precise and accurate measurements of such minute and refractive bodies are difficult. The basal, wider end of the spore contains a vesicle

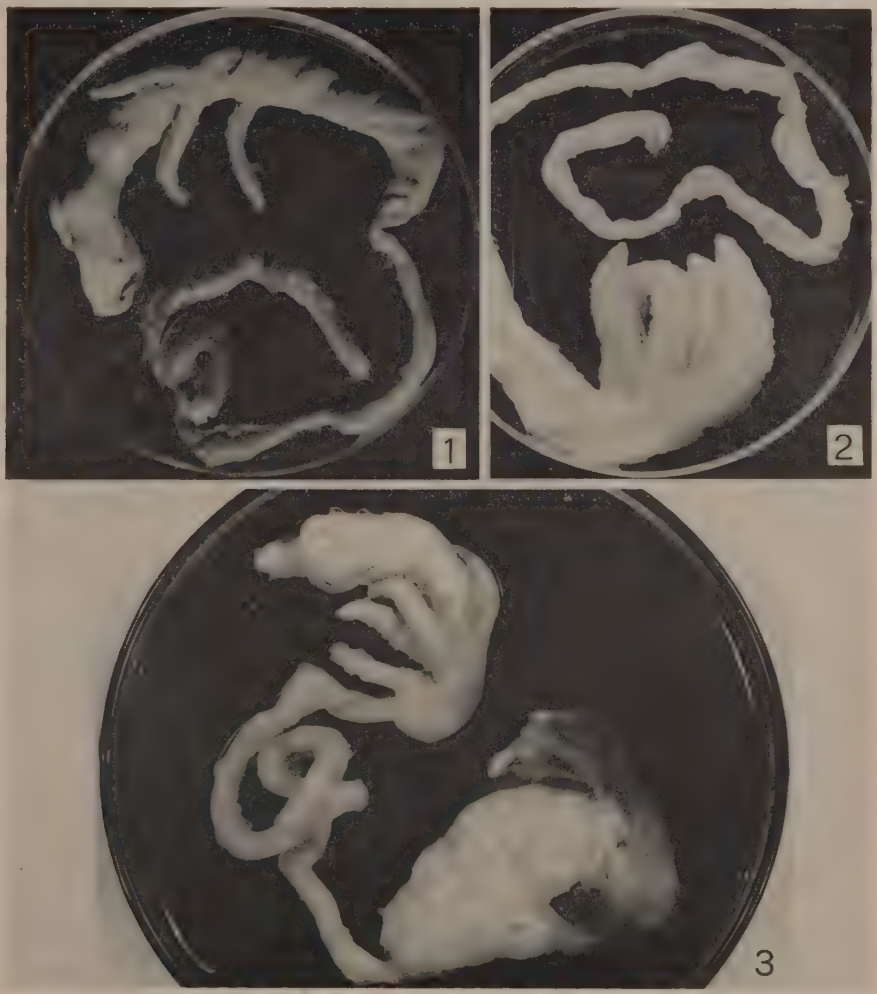

PLATE I

FIGURE 1. Digestive tract of *P. americanus,* normal condition, in a Petri-dish, 9.5 cm. outside diameter.

FIGURE 2. Pyloric ceca and intestine of infected fish, same magnification as Figure 1.

FIGURE 3. Digestive tract of infected fish, same magnification as Figure 1.

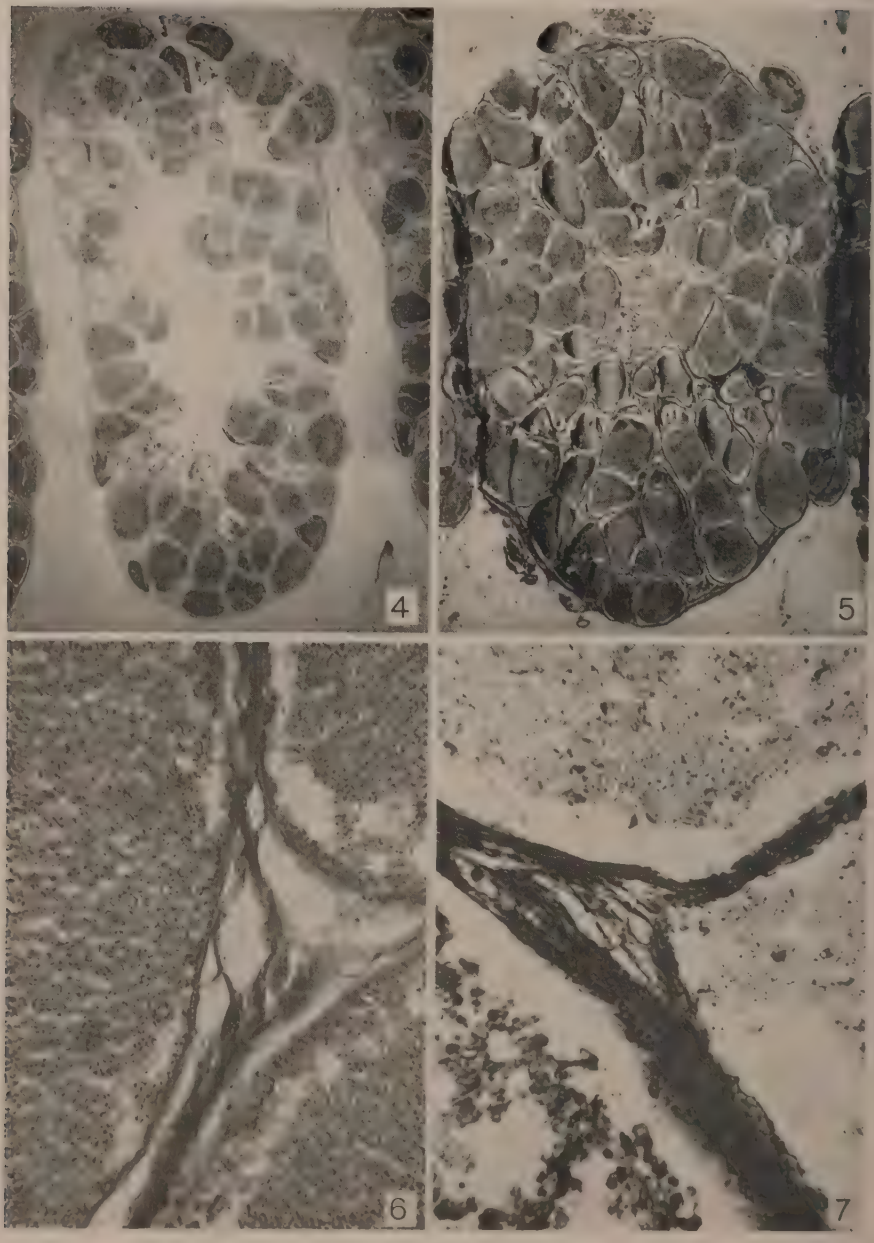

PLATE II

that may occupy almost one-half the length of the spore. The apical end also contains a smaller vesicle, while the central portion contains a band of chromatic material, often in the form of strings of particles or granules, and a single strand extends to the apical end of the spore.

Discussion

The most comprehensive account of the Microsporidia is the monograph by Kudo (1924). He gave a review of morphology and life-cycles, with a description and taxonomic survey of all previously described species. In a later study, Kudo (1944) stated (p. 38), "The early phases of the development of Microsporidia have not been seen in many species. In a few instances of experimental infection, certain portions of the development have been seen, but in no case has observation in life been carried through." It is generally agreed, however, that the life-cycle of a microsporidian species consists of two distinct phases or stages: a multiplicative stage, schizogony, and a spore-forming stage, sporogony. In the multiplicative phase, cell division is rapid and according to certain investigators it may result from binary fission following nuclear division or multiple fission if nuclear division is rapid and cytoplasmic division is delayed. It has been suggested (Kudo, 1924) that in certain species the schizonts (meronts of Stempell, 1902) are not motile and as a consequence that the progeny of a sporoplasm remains in the host-cell and that all the spores formed in that cell are derived from the initial parasite. But usually the infection is invasive, with diffuse infiltration of tissue, and such a condition could result from either the penetration and dispersal of enormous numbers of planonts or by the liberation of schizonts and their ingestion by leukocytes or macrophages which accumulate at sites of inflammation and which could transport the schizonts to other areas and extend the infection. At the end of the schizogonic phase, sporonts are formed but the factors involved and details of the phenomena which result in the formation of sporonts are equivocal. Supporting the observations of Weissenberg (1914), Debaisieux (1920) and Guyénot and Naville (1922), Kudo (1946, p. 162) stated, "In the Microsporidia, autogamy appears to initiate the spore-formation at the end of schizogonic activity."

In the present study, the inability to obtain experimental infection of fishes has precluded observations on the multiplicative phases of the life-cycle. But this inability has raised important and perplexing problems. Since fishes become infected when only 50 mm. in length and when the food consists of small invertebrates, it seems probable that a second or intermediate host may be required in the life-cycle of the parasite. Such an invertebrate may be merely a paratenic or transport host, which ingests spores from a dead fish and is then eaten by a small flounder, or it may be essential in the completion of the life-cycle of the parasite. Since

Figure 4. Photomicrograph of cross-section of the intestine shown in Figure 2. Note lack of digestive epithelium and disintegration of the gut wall.

Figure 5. Photomicrograph of cross-section of one of the pyloric ceca shown in Figure 2. The infection is more intense in this area than in the intestine.

Figure 6. Photomicrograph of section of pyloric cecum, greater magnification, to show connective tissue capsular wall of the cyst and number of spores.

Figure 7. Photomicrograph of section of pyloric cecum, showing walls of cysts and adjacent nuclei and cells.

small crustaceans are carnivorous and constitute a considerable part of the food of small fishes, they become suspect. According to the account of Frederick E. Smith, (The Benthos of Block Island Sound: Ph.D. thesis, Yale University, 1950, 213 pp. and appendices), 75% of the food of the winter flounder consisted of amphipods and 43% of the amphipods were *Leptocheirus pinguis*.

Other questions also arise: why are certain infections mild while others become massive? Do older fishes develop resistance to infection and restrict the invasive activity of the parasite? Why do the cysts manifest such uniformity in size? Finally, in view of the statements of Reichenow (1929) and Poisson (1953) that generic concepts are tenuous, what is the status of *Glugea* and does the species, *stephani*, belong in that genus? The answers to these and other questions await further investigation on the life-cycle of the species.

Summary

A microsporidian infection of the blackback or winter flounder, *Pseudopleuronectes americanus*, has been investigated. It was first noted at Woods Hole, Massachusetts by Linton (1901) and may be identical with similar infections of European flounders reported by Hagenmüller (1899), who described the parasite as *Nosema stephani*. Woodcock (1904) transferred the species to *Glugea*, a genus erected by Thélohan (1891) to contain a parasite of the striated muscle in *Cottus scorpio* and *Callionymus lyra*, which he described as a new species, *Glugea microspora*. Gurley (1893) predicated that *G. microspora* is identical with *Nosema anomala* (Moniez, 1877), although he recognized *Glugea* as a valid genus, distinct from *Nosema*. In New England the infection is common in *P. americanus*. The incidence and intensity of infection in fishes of different sizes and from different geographical regions are reported, together with an account of the resultant pathology. Attempts to obtain experimental infection of fishes have not been successful and the life-cycle of the parasite remains unknown.

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RESULTS OF TRIALS WITH A NEUSTON NET IN THE GULF OF GUINEA

by

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Abstract

A neuston net was tried out in the Gulf of Guinea to determine its effectiveness for capturing larval tunas and nekton on which tuna feed. The nylon net (length, 3.9 m; rectangular mouth, 30 cm x 15 cm; mesh, 0.6 mm square) was suspended on a framework between two water skis and towed at speeds of 2 to 12 knots. The trials indicated that: (1) many organisms, particularly the larvae and juveniles of Auxis, were concentrated near the surface and could be captured with the net; and (2) the species and size composition of the animals caught were different than in collections made by light attraction methods. The capture of some small fish, when the neuston net was towed through schools of feeding tunas, indicates that this device may be useful for sampling tuna forage.

INTRODUCTION

Neuston, the organisms inhabiting the surface water or surface film, may be one of the most important faunas of the world's oceans. Because many of the organisms are fast, agile swimmers and possess acute optical and auditory senses, they have not been effectively sampled by conventional methods. Dr. Peter M. David, of the National Institute of Oceanography, Wormley, England, recently designed an apparatus which can be towed at high speed to better sample neuston (David, P. M. 1963. The neuston net. N.I.O. Internal Report B 3). We decided to construct and test the net because of our interest in the ecology of the tunas, which are part of the neuston as larvae and juveniles and feed on it as adults. The results of the first trials with this net are reported here.

DESCRIPTION OF THE NEUSTON NET

The neuston net is essentially a conical nylon net suspended between a pair of keeled water skis, each about 7 feet long and 1 foot wide (Fig. 1). Each ski is reinforced by two 2- by 4-inch hardwood boards bolted to the upper edges of the ski and extending along almost its full length. The skis are joined together by four 1- by 4-inch wooden cross members. The front cross member is raised 10 inches above the skis to avoid disturbing the water ahead of the net. The keels are of 3/4-inch marine plywood, 74 inches long and 34 inches deep. One keel is attached to the inside edge of each ski, and is braced by three metal struts that extend from the bottom of the keel to the outside edge of the ski.

The net is 3.9 m long; its rectangular mouth is 30 cm wide and 15 cm high; in our model the mesh is 0.6 mm square. The net is attached to a

Reprinted from
OCEAN SCIENCE AND OCEAN ENGINEERING
Transactions of the Joint Conference,
Marine Technology Society and American Society of Limnology and Oceanography
Washington, D. C., June 1965

steel frame that is mounted with the lower edge of the net submerged to a depth of 4 inches when the sampling device is at rest on the water. While being towed, the net mouth is only partly submerged; the depth varying with sea conditions.

OPERATION OF THE NEUSTON NET

The net was towed from a light boom, 12 feet long, located near the bow of the ship. Adjustments in the towing bridle allowed the net to be fished from either side of the ship. The towing line was of 1/2-inch nylon, sufficiently long for the net to be fished in water undisturbed by the ship's wake. The net was lowered into and recovered from the sea with a hook from the cargo boom, usually while the ship was underway. The net was used at 30 stations (a total of 42 tows, 37 of which were at night); tows were made at two speeds at 10 of the stations and at three speeds at one station. All tows were for 15 minutes.

SIZE OF CATCH IN RELATION TO TOWING SPEED

The numbers and kinds of organisms caught at the station where the net was towed at 2, 5, and 12 knots (GERONIMO station 35, 7 August 1964, 00633 W - 0432 N) are shown in Figure 2. The volume of water filtered, although not measured, appeared to be roughly proportional to the distance the net traveled. Thus the faster tows at this station caught proportionately more specimens (particularly of Auxis) and species although data from other stations did not indicate any direct relationship between towing speed and number of species caught.

COMPARISON OF SAMPLES: THE NEUSTON NET VERSUS A 1-METER PLANKTON NET

Prior to sampling with the neuston net at each station, a conventional 1-meter plankton net (0.280 mm mesh) was towed for 15 minutes at 2 knots. Throughout most of these tows, the plankton net was kept about 1 foot or more below the surface of the water but visible from the deck of the ship. The neuston net was much more efficient than the plankton net in the capture of larval and juvenile Auxis, which comprised the bulk of the fish sampled (Figure 3), largely because it could be towed much faster. The numbers of Auxis caught were closely comparable when both nets were towed at 2 knots. This is quite surprising when one considers that the functional mouth opening of the meter net (7854 cm^2) is about 33 times larger than that of the neuston net (240 cm^2). It appears that the Auxis larvae and juveniles were concentrated very near the surface.

SIZES OF SPECIMENS CAUGHT IN RELATION TO TOWING SPEED

Although the neuston net might be expected to capture a relatively greater proportion of large fish (i.e., faster swimming individuals) at the faster towing speeds, lengths and numbers of Auxis caught at different speeds did not support this hypothesis (Table 1). A plausible explanation is that the surface population of larval and juvenile Auxis was effectively sampled by the neuston net (and the meter net) at the slowest towing speed. Data on other species was too limited to permit a judgment as to the ability of the neuston net to capture larger individuals at higher towing speeds.

COMPARISON OF NEUSTON NET COLLECTIONS AND NIGHT-LIGHT COLLECTIONS

After most night hauls with the neuston net, a 1000 watt light was placed in the water to attract fish and invertebrates. Dip nets were then used to capture animals approaching the light during a 60- to 80-minute period. Data on the number and species of organisms collected during four pairs of night-light and neuston net collections show many differences (Table 2). Large numbers of lanternfishes (Myctophidae) were taken by both techniques, although the night-light method yielded the most. Of the five species of lanternfishes collected, Hygophum macrochir was numerous in neuston net samples, but absent in the night-light collections (presumably because this species is not attracted by the light).

The lanternfishes taken in the neuston net were smaller than those dip-netted under the light. This difference could be the result of: (1) inability of those using the dip nets to see small specimens under the light; (2) a collection bias in favor of large obvious specimens; and (3) selective attraction of large lanternfish to the light.

Flying fish and squid were taken by night-lighting but not by the neuston net. These animals were strongly attracted to the light and easily collected. Their absence from the neuston net samples presumably resulted from an ability to avoid the net or a tendency to avoid the near surface, except where the light was shining.

CATCHES IN A NEUSTON NET TOWED THROUGH SURFACE SCHOOLS OF TUNA

On four occasions, the neuston net was towed (at 12 knots) in the daytime through surface schools of tuna which were in an apparent feeding frenzy amongst large numbers of other small fishes. Nothing was caught on two of these occasions. On two occasions, however, fishes were captured:

(1) GERONIMO station 63, 12 August 1964, 0358 N - 00344 W. One tow through a school of yellowfin tuna yielded two large specimens of anchovy, Anchoviella guineensis Blache, 70-80 mm in standard length;

(2) GERONIMO station 57, 11 August 1964, 0453 N - 00432 W. The first tow through a mixed school of yellowfin and skipjack tunas yielded 157 specimens of Sardinella aurita Cuvier and Valenciennes, 30-40 mm in standard length; a second tow yielded 36 specimens of S. aurita, 30-40 mm in standard length.

Anchovies and sardines of about these same sizes were common in the stomachs of the tunas sampled during the cruise.

On the basis of these results, neuston net sampling through tuna schools is being continued, on the tentative assumption that it is sampling the tuna forage organisms.

Table 1. Length-frequency distribution of Auxis collected in a 1-meter net, and in a neuston net towed at different speeds. Catches are adjusted to a towing distance of 2 nautical miles.

Standard Length (mm)	Gear and Towing Speed			
	Meter Net	Neuston Net		
		2 knots	5 knots	12 knots
7.5	3	1	-	-
8.0	3	1	-	-
8.5	4	-	-	-
9.0	3	-	-	-
9.5	4	1	-	-
10.0	3	4	1	5
10.5	6	2	1	3
11.0	2	2	-	4
11.5	7	3	2	4
12.0	13	3	2	6
12.5	15	4	8	7
13.0	7	4	8	8
13.5	12	10	16	11
14.0	13	13	9	15
14.5	17	17	13	15
15.0	22	19	15	16
15.5	20	19	19	21
16.0	8	15	12	17
16.5	13	20	23	12
17.0	11	28	13	15
17.5	8	30	12	14
18.0	10	18	12	11
18.5	15	14	12	7
19.0	10	13	7	5
19.5	1	13	6	3
20.0	2	8	8	5
20.5	2	3	2	3
21.0	2	4	3	2
21.5	3	-	3	2
22.0	1	1	-	1
22.5	-	3	1	1
23.0	1	3	1	1
23.5	-	-	-	2
24.0	1	3	-	-
24.5	1	1	-	1
25.0	1	-	-	-
25.5	-	3	-	-
26.0	-	1	-	1
26.5	-	1	-	2
27.0	-	-	-	1
27.5	-	-	-	-
28.5	-	1	-	-
31.0	-	1	-	-

Table 2. Number and (in parentheses) length range (mm) of animals collected with a neuston net and with a night light at four stations, during GERONIMO cruise 4, 1964. All tows with the neuston net were for 15 minutes at 5 knots; the night light was used for 80 minutes at station 30 and for 60 minutes at stations 39, 61, and 78.

Species	Method of Collection	
	Neuston Net	Night Light
Station 30		
Invertebrates		
Ommastrephes pteropus Steenstrup	-	4
Onychoteuthis banksi (Leach)	-	1
Fishes		
Myctophum affine (Luetken)	-	4 (35-40)
M. nitidulum Garman	-	6 (43-73)
M. asperum Richardson	-	38 (50-73)
M. sp. (M. affine and/or M. nitidulum; damaged specimens)	38 (15-60)	-
Exocoetus volitans Linnaeus	-	45 (58-180)
Oxyporhamphus micropterus (Cuvier and Valenciennes)	-	13 (102-135)
Hirundichthys affinis (Guenther)	-	1 (121)
Cypselurus exsiliens (Linnaeus)	-	2 (210-225)
Eel Larvae	1 (115)	-
Station 39		
Invertebrates		
Ommastrephes pteropus Steenstrup	-	2
O. sp.		
Fishes		
Myctophum asperum Richardson	1 (53)	29 (40-70)
M. nitidulum Garman	1 (40)	3 (43-71)
M. affine (Luetken)	4 (15-42)	1 (42)
M. sp. (M. affine and M. nitidulum; damaged specimens)	9 (15)	-
Hygophum macrochir (Guenther)	1 (47)	-
Coryphaena equiselis Linnaeus	-	1 (80)
Oxyporhamphus micropterus (Cuvier and Valenciennes)	-	9 (90-141)
Exocoetus volitans Linnaeus	-	5 (118-135)
E. obtusirostris Guenther	-	2 (50-51)
Cypselurus exsiliens (Linnaeus)	-	5 (139-178)
Station 61		
Invertebrates		
Ommastrephes pteropus Steenstrup	-	1
Fishes		
Centrobranchus nigroocellatus (Guenther)	-	1 (30)

Table 2. (cont'd)

Species	Method of Collection	
	Neuston Net	Night Light
Station 61 (cont'd)		
Myctophum asperum Richardson	16 (14-63)	27 (40-72)
M. nitidulum Garman	-	4 (60-73)
M. affine (Luetken)	6 (14-45)	-
Exocoetus obtusirostris Guenther	-	2 (44-114)
Parexocoetus brachypterus (Richardson)	-	1 (62)
Eel larvae	1 (64)	-
Station 78		
Invertebrates		
Ommastrephes pteropus Steenstrup	-	5
Phyllosoma	10	-
Stomatopoda	7	-
Porpita sp.	1	-
Physalia sp.	-	1
Fishes		
Myctophum asperum Richardson	33 (15-59)	11 (40-56)
M. affine (Luetken)	-	1 (38)
M. nitidulum Garman	-	2 (50-58)
M. sp. (M. affine and M. nitidulum; damaged specimens)	15 (15-38)	-
Hygophum macrochir (Guenther)	6 (30-46)	-
Centrobranchus nigroocellatus (Guenther)	2 (26-45)	1 (34)
Oxyporhamphus micropterus (Cuvier and Valenciennes)	-	8 (85-135)
Parexocoetus sp.	1 (67)	-
Exocoetus obtusirostris Guenther	-	2 (130-160)
Cypselurus sp.	-	1 (200)
Hirundichthys affinis (Guenther)	-	7 (240-250)
Coryphaena equiselis Linnaeus	1 (31)	3 (37-50)

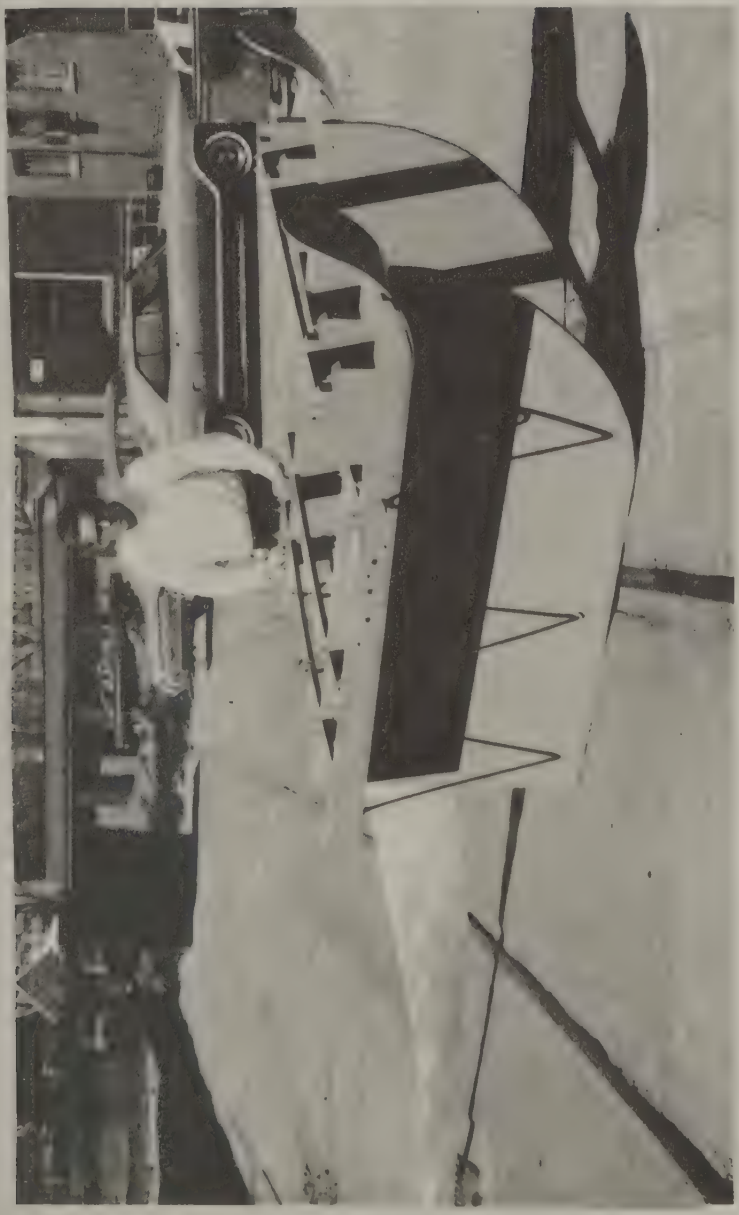

Figure 1. A neuston net.

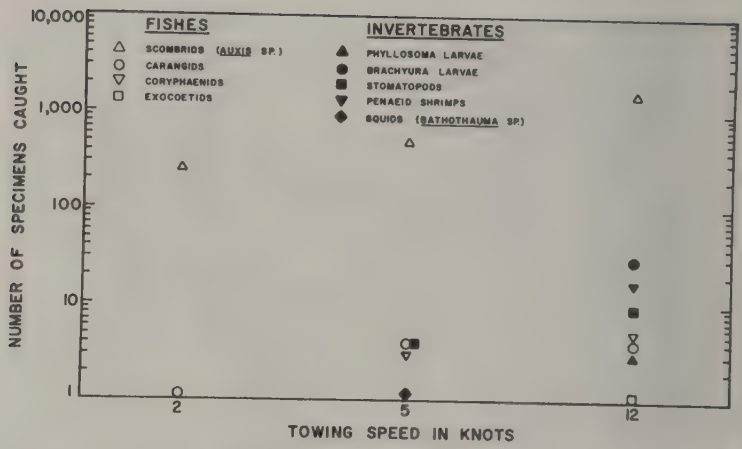

Figure 2. Numbers of invertebrates and fishes caught in 15-minute tows of a neuston net at 2, 5, and 12 knots.

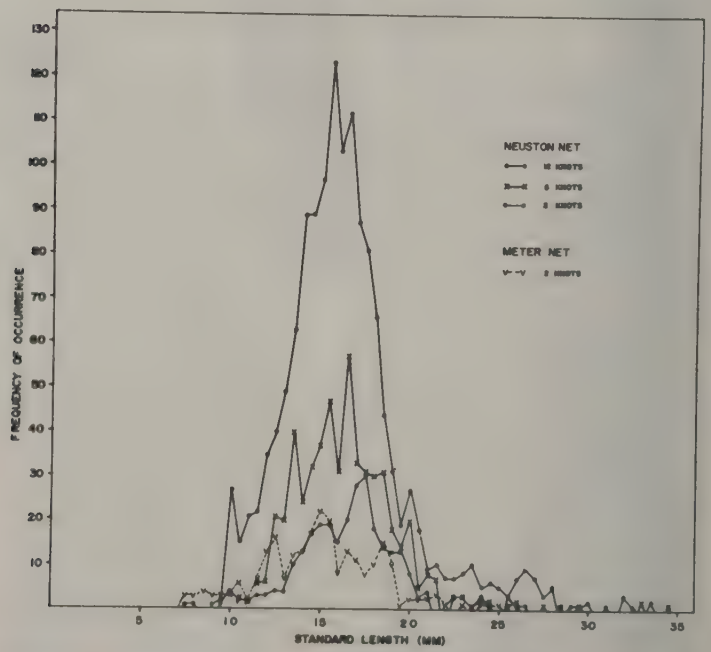

Figure 3. Length-frequency distribution of Auxis taken in a 1-meter plankton net haul and in 3 hauls of a neuston net at different speeds. Duration of each tow was 15 minutes.

"Reprinted from *Proceedings of the Seventeenth Annual Conference, Southeastern Association of Game and Fish Commissioners,* September 29, 30, October 1, 2, 1963, held at Biloxi, Mississippi"

MULTIPLE UTILIZATION OF GULF COAST ESTUARIES

By
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ABSTRACT

It is estimated that some 7500 square miles or 4,800,000 acres of estuarine area exist on the periphery of the Gulf of Mexico. Gulf commercial catches of fish and shellfish in 1960 consisted of over 1 billion pounds of estuarine dependent species. The contribution of Gulf estuaries toward these catches amounted to approximately 230 pounds per acre. The evaluation of estuaries is discussed in terms of total production including other forms of organic matter. Beneficial and detrimental uses of shallow-water coastal areas are cited.

In selecting topics for the marine panel we chose to highlight the present status of estuaries, their economic and biological benefits, and some of the research being directed toward them. Discussions of fish, oysters, and shrimp were included because they are items demanding the greater portion of estuarine research effort in recent years. They also constitute the most obvious product associated with coastal and shallow water zones. Man's pleasure and relaxation is frequently related to these areas, so a discussion of recreational aspects is warranted when considering the multiple utilization of estuaries. Uncontaminated estuaries are becoming scarce and for that reason a portion of the panel discussion is devoted to pollutant dispersal.

In addition to the panel reports on fisheries, recreation, and pollution, we shall examine briefly some other uses of estuaries and the direction which research is taking. Recent scientific advances confirm the necessity for fundamental biological research as a means of evaluating the estuarine resource. Attention is now being paid to the mechanics of self-fertilization and nutrient utilization. Also being considered are possible ways and means of modifying or controlling engineering structures and projects so often detrimental to the resource.

Most estuarine research in the Gulf of Mexico area is motivated by a quest for knowledge regarding the dependence of commercially important species upon estuaries. In working toward this objective spe-

cialized studies in the physical, chemical, and biological disciplines play an important role. Estuarine problems and research viewpoints may be illustrated by commenting briefly on the four following questions:

1. What are estuaries?

A dictionary definition states that an estuary is "A passage, at the mouth of a river or lake, where the tide meets the river current; more commonly, an arm of the sea at the lower end of a river." Ketchum (1953) and Pritchard (1952) developed definitions based on the variety of coastal shallow-water systems encountered over a wide geographical area. At a recent estuarine conference features of these definitions were modified to produce the following:

> "Estuaries are those shallow waters with fluctuating salinities that differ from those of the adjacent sea. Usually, but not always, they are semi-enclosed bodies of water. Physical factors resulting from the mixing of fresh and salt waters and the resulting nutrient enrichment and high productivity of these waters constitute the unique features of estuaries."

Each ecologist has his own definition of an estuary; nevertheless, the one above takes into account the most salient features of those estuaries in southeastern United States. It is particularly important in the Gulf of Mexico to consider also the economic significance of the vast areas of salt marshes and alluvial plains which are adjacent to estuaries. These add to the productivity of estuaries by supplying structure, nutrients, and periodic habitat for estuarine animals.

2. What is the value of estuaries?

It would appear that in recent years little thought has been given to the present and potential value of estuarine areas except as natural features available for conversion to industrial or real estate sites. Odum (1961) stated that estuaries, plains, and marshes are among the most naturally fertile areas of the world. Planimeter determinations show that approximately 23,000 square miles of this type of coastal complex exists on the periphery of the Gulf of Mexico. There are approximately 7,500 square miles of estuarine area and 15,500 square miles of marsh area.

In 1960 the commercial catch of fish and shellfish landed at ports of the Gulf states amounted to 1,266,000,000 pounds, having an ex-vessel value of $85,000,000 (Power 1960). Five species which are known to be estuarine-dependent (menhaden, shrimp, crabs, oysters, and mullet) constituted 89.3 percent of the catch or 1,131,000,000 pounds. This amounts to an estimated annual contribution of 230 pounds of marketable fish and shellfish per acre of estuarine area, after discounting 27,000,000 pounds of shrimp (heads-on) caught off the Mexican coast and landed in United States ports (U. S. Fish and Wildlife Service 1960). Doubtless, the estimate varies considerably between estuaries, depending upon depth, salinity gradient, food availability, and other factors. It does not account for sport fish catches or forage species not utilized directly by the fisheries and is therefore, minimal.

Although an estimate of 230 pounds of fishery products per acre per year is a fairly impressive yield for waters not fertilized artificially, it is small in comparison to the yield of lower tropic biota. For instance, Odum (personal communication 1963) stated that the net primary productivity of coastal estuaries in the vicinity of Sapelo Island, Georgia is 2400 grams of dry organic matter per square meter per year. This amounts to approximately 21,000 pounds or over ten tons per acre per year. The yield per acre is about four times that of the average annual United States corn crop including stalks and roots. Assuming that the organic yield in Gulf estuaries approaches that on the Georgia coast, it becomes evident that the resource remains relatively untapped. The problem then is not one of seeking means by which productivity may be increased but rather of seeking better utilization of the available resource and protecting that which exists.

Most estuarine research reports have dealt with identification, abundance, and distribution of forms or groups of taxa. Few, if any, have calculated total or long-term value by the methods which industry

uses in arriving at estimates of capitalized value. Estuaries have too seldom been considered a thing of economic value. The worth of these areas cannot be based completely upon the harvest of species originating therein. The evaluation must also include all present and potential production of organic material plus estimates of monetary benefit derived from recreation.

The demand for additional protein from the sea in the United States is not great at present. The average per capita consumption of commercially caught fish and shellfish is 10.5 pounds per year (Power 1962). The U. S. population is expected to increase from the present 190,000,000 to 225,000,000 by 1975 and to 331,000,000 by the year 2000 (Investor's Reader 1963). Eventually—perhaps within 40 years—increased production of protein will be necessary regardless of the source. In view of these predictions it is clear that the true worth of estuaries as potential protein producers should be determined and publicized.

3. How are estuaries being used?

In addition to the use of estuaries for recreation, biological production, and other positive benefits, there are uses which are detrimental. Some of these may appear temporarily to benefit the human population. It is usually more convenient and less expensive to pump industrial and domestic refuse directly into an adjacent body of water than to dispose of it in some other fashion. Attractive cities are built at the water's edge on land which has been pumped from the estuary. It then becomes necessary to construct connecting fills, causeways, and bridges, disrupting the normal circulatory regime and creating stagnant pools which are no longer estuaries. The present rate of progress in reclaiming "waste lands" such as marshes and intertidal plains so necessary in the production of marine animals will eventually destroy these areas as a resource. Such misuse will continue, however, until the value of estuaries in their natural state is calculated and recognized.

4. How can we guarantee continued estuarine benefits?

The approach to this question can be logically defined but the steps involved are numerous and painstaking. First, there is a need for research which will result in a firm knowledge of the value of estuaries. Here we cannot think in terms of esthetic values. By the dictates of our economic society, estuarine values must be expressed in dollars, since estuaries are frequently in competition with profit-making industrial enterprises. The estimate of dollars must be derived from the amount of organic material produced, including fish and shellfish, but also including all organic material whether or not it is presently utilized in full.

Second, our knowledge must reach a point at which we can predict accurately the effect that an engineering project will have on an estuary in terms of organic production and in terms of dollars. As this knowledge is gained, we must disseminate it to governing agencies and to those agencies engaged in estuarine rearrangement. This should tend to strengthen and encourage stricter adherence to the Fish and Wildlife Coordination Act.

The future of estuaries need not be so dismal as present forecasts infer. The ensuing panel reports on shrimp, oysters, recreation, and contamination are examples of research now being accomplished. They represent a portion of the initial step which has to be taken in evaluating coastal, shallow water systems. In addition five laboratories of the U. S. Bureau of Commercial Fisheries have plans for coordinated estuarine research. The laboratories are located in Texas, Florida, Georgia, and North Carolina. The first phase of that study will consist of determining primary productivity in estuarine systems of the Gulf and South Atlantic Coasts. The study will begin in January 1964 as a part of the International Biological Year. Estuarine research is presently under way at each of these laboratories and it is anticipated that coordinated studies of primary productivity will be expanded to encompass other aspects of estuarine problems.

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Chesapeake Science Vol. 6, No. 4, pp. 233–234 December, 1965

Bottom Samplers for Estuarine Research[1]

John L. Taylor

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ABSTRACT: The designs of a bucket dredge, a bottom drag, and a coring tube are presented. These devices are designed for small-boat operations in shallow water areas in estuaries.

and subsamples for sediment analysis can be obtained when the dredge is emptied. The dredge must be towed slowly, and may be fastened to ½-inch line or $^{3}/_{32}$-inch hydrographic cable if a small winch is used. A low towing angle is desirable

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ABSTRACT: The designs of a bucket dredge, a bottom drag, and a coring tube are presented. These devices are designed for small-boat operations in shallow water areas in estuaries.

Benthic research is beset with sampling problems because of differences in bottom texture, vegetation, water depth, species distribution, and certain operational considerations. For example, no single bottom sampler exists today that can obtain quantitative samples over a wide range of sediment types. At best, the capabilities of available instruments must be weighed against operating conditions to select appropriate gear for each situation (Jones, 1961; Hedgpeth, et al., 1957; Holme, 1964; Hopkins, 1964). In estuaries the question of choosing samplers is especially complicated because of the frequent extreme variations in physical and biological conditions. Often it is necessary to use several different bottom samplers in combination for benthic studies within a single embayment.

Three sampling devices[2] are depicted here; they have been used by the Bureau of Commercial Fisheries Biological Station, St. Petersburg Beach, Florida, primarily in an investigation of estuaries along the west coast of Florida. They have also been used to help locate commercial species and make biological collections on bottom lands proposed for development. Although no new mechanical concepts are presented, these tools incorporate features of design, durability, and simplicity that may be of service to others concerned with benthic ecology.

The Bucket Dredge:—This is constructed of stainless steel and holds about 15 quarts of sediment (Fig. 1). It was modified from a similar piece of equipment used by Dr. E. Lowe Pierce for a study of lancelets in coastal waters (Pierce, 1965). It has been used at this Station to survey the infauna and sediments of Tampa Bay. In operation, the dredge shears off the upper 1½ inches of sediment, and readily obtains samples from soft and mixed bottoms, compact sand, substrate composed of coarse shell fragments, and bottoms supporting moderately heavy growth of marine vegetation. Underwater observations with SCUBA gear have shown that the dredge does not pull out of soft and firm sediments, but some skipping may occur on hard sand bottoms. Washout of sediment presents no problem if the sampler is raised slowly, and subsamples for sediment analysis can be obtained when the dredge is emptied. The dredge must be towed slowly, and may be fastened to ½-inch line or $\frac{3}{32}$-inch hydrographic cable if a small winch is used. A low towing angle is desirable, and about 5 feet of line should be played out for each foot of water. It has been used successfully from the intertidal zone down to a depth of 7 fathoms, and can be handled by one man. The dredge can be purchased for $50.00, and is suited to small-boat operations if a motor capacity of at least 35 horsepower is available.

The Bottom Drag:—This is a qualitative sampler that has been used in grass beds for collec-

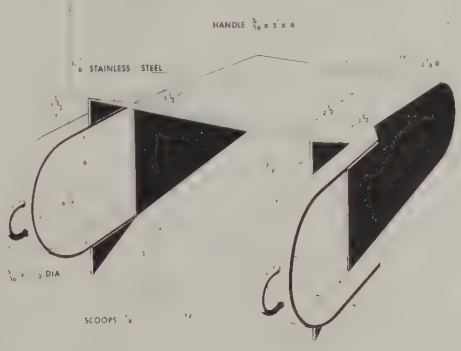

Fig. 1. A bucket dredge.

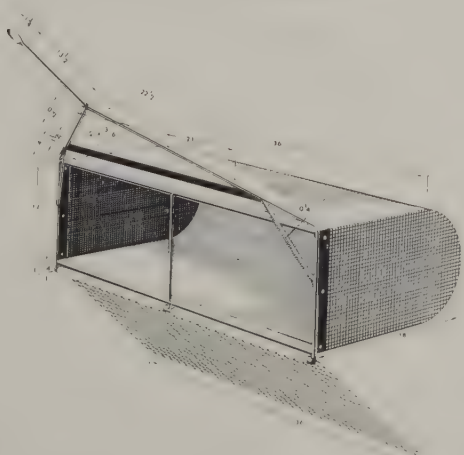

Fig. 2. A bottom drag with stainless steel frame, nylon net, and chafing gear.

[1] Contribution No. 22, Bureau of Commercial Fisheries Biological Station, St. Petersburg Beach, Florida.

[2] Illustrations by Mr. John Webb, Clearwater, Florida.

Fig. 3. A shallow-water coring tube.

tions of small crustaceans and juvenile fishes (Fig. 2). On bare substrate the drag takes mobile forms such as bottom fish, shrimp, and crabs. These forms are closely associated with the infauna, and for this reason the drag has often been used in conjunction with the bucket dredge. The frame is stainless steel, and the bag is of ⅛-inch-mesh nylon netting. The bottom of the bag is protected during operation by heavy, coarse mesh chafing gear as illustrated. The frame of the drag was constructed for $45.00, and costs for buying and fixing the netting amounted to about $10.00. The drag is rigged in the same manner as the bucket dredge and tows well at slow speeds. On clear bottom, 3-minute tows are taken, and in grass beds the bag normally fills in about 1 minute. It can be handled easily by one man from a small outboard motor boat.

The Shallow-Water Coring Tube:—A quantitative sampler (Fig. 3), this coring tube extracts a well-formed, 2½-inch diameter core in unconsolidated substrates except those composed primarily of coarse shell fragments. It is stainless steel and is equipped with a flange, 6½ inches from the bottom, which limits sampling to that depth. A stopper at the top prevents water from entering the coring tube and facilitates removal of the sample from the substrate. Cores are extruded with a plunger fashioned from dowling and tipped with a rubber stopper (not illustrated). Total cost for the sampler is $20.00. This corer is manually operated, and its use is limited to a convenient depth for wading or about 4 feet. It has been used to sample intertidal sediments for ecological studies, and to evaluate the biomass of infauna on riparian land proposed for commercial development. With the coring tube and miscellaneous collecting gear loaded aboard a small skiff, a field party of two can move about conveniently in sampling shallow water and intertidal habitats.

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[Reprinted from Publ. Institute of Marine Science, Texas, Vol. 10, June, 1965]

Vertical Distribution of the Planktonic Stages of Penaeid Shrimp[1]

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Abstract

In an attempt to describe the vertical diurnal distribution of planktonic stages of penaeid shrimps, short research cruises into the Gulf of Mexico were made in June, July, September, and November 1963. The plankton was sampled systematically at a station 50 miles south of Galveston, Texas, where water depth approached 36.5 meters. Samples were obtained with a Clarke-Bumpus sampler at 4-hour intervals at each of three depths: 2, 18, and 34 meters. Bathythermograph casts were made prior to or at the completion of each collection.

During the first three cruises when temperature profiles and visual observations indicated a vertically stable water mass, catch data grouped for all stages indicated that planktonic penaeids were most frequent at and below mid-depth. Data arranged by developmental stage indicated, however, that protozoeal stages were found most frequently near the bottom whereas postlarval stages were at or above mid-depths. Each planktonic stage extended its distribution into the surface layer either just prior to or after darkness.

In November, when temperature profiles and visual observations indicated a vertically unstable water mass, planktonic-stage penaeids were more or less homogeneously distributed throughout the water column. There was no evidence of movement into the surface layer at night by any planktonic stage.

Introduction

Biologists at the Bureau of Commercial Fisheries Biological Laboratory in Galveston, Texas are engaged in a broad investigation of the seasonal as well as areal distribution and abundance of larval and postlarval penaeid shrimps in the northwestern Gulf of Mexico. Over the past two decades, studies of all phases of the life history of Gulf Penaeidae have received greater impetus as the commercial importance of many members of this family has increased. Prior to this period, information concerning young or larval penaeids in the Gulf of Mexico was restricted primarily to the work performed by Pearson (1939). He described the larval and postlarval stages of the white shrimp, *Penaeus setiferus*, and those of several other important penaeids occurring in the Gulf, including information on their growth and distribution as well. More recently, Dobkin (1961) outlined in detail the larval and postlarval stages of the pink shrimp, *Penaeus duorarum*, and Renfro and Cook (1963) described the early larval stages of the seabob, *Xiphopeneus krøyeri*. Very little information is available, however, concerning early stages in the life history of the brown shrimp, *Penaeus aztecus*, which in recent years has become the Gulf's most valuable commercial species.

It is generally believed that brown shrimp spawn in the open Gulf, sometimes as far as 110 miles offshore in depths to 110 meters. The eggs, slightly more dense than sea water, are deposited on the bottom. After hatching, the young planktonic shrimp develop through a series of three larval (nauplial, protozoeal, and mysis) and several postlarval

[1] Contribution No. 191, Bureau of Commercial Fisheries, Galveston, Texas.

stages. They enter the bays as advanced postlarvae where they grow rapidly to subadult size and subsequently migrate offshore to repeat their life cycle.

The movement of postlarval brown shrimp into estuarine nursery areas along the northwestern Gulf of Mexico appears to be a prerequisite for the production of their greatest biomass. Whether the planktonic stages are capable of extensive shoreward movement, whether water currents are largely responsible for their transport inshore, or whether both factors are important, is not known. Although Gurney (1924) and Koxon (1934) felt that the advanced stages of decapod larvae are not as much at the mercy of currents as might be supposed, the role of water currents in the distribution and survival of planktonic forms has been of considerable concern for a number of years. Colton (1959) provided evidence that the transport of planktonic fish eggs and larvae from the cooler waters of Georges Bank (Gulf of Maine) into the warmer Gulf Stream resulted in mass mortality. In a similar manner, water currents over the continental shelf in the northwestern portion of the Gulf of Mexico may be of considerable importance in the survival of planktonic penaeids. Because current direction and velocity may vary with depth, the importance of water currents can be properly assessed only after the position of the organism within the water column is known. This paper presents the results of four attempts to determine the vertical distribution of the planktonic stages of penaeid shrimp in the water column.

Materials and Methods

Short cruises with the Laboratory's research vessel were conducted in June, July, September, and November 1963 to a station 50 miles south of Galveston where the water depth approaches 36.5 meters (Fig. 1). Results of sampling in 1961 and 1962 had indicated that planktonic stages of penaeid shrimp usually could be found at this station at these times.

Plankton collections were made with a Clarke-Bumpus sampler whose frame was enlarged so that two nets could be mounted instead of one (Fig. 2). The mouth of each net had a cross-sectional area of 120.6 cm^2. Nets of No. 3 bolting silk (aperture 0.33 mm) were employed throughout the first three cruises, whereas, No. 2 nylon nets (0.36 mm) were used for the November collections. Since the samplers could be opened and closed at the desired depths, contamination with material from other depths while lowering or retrieving the gear was believed negligible.

Sampling covered 36 hours during the first cruise and 14 hours during each of the other three. Collections were made at 4-hour intervals at three depths: 2, 18, and 34 meters. Although samples were not taken at all depths simultaneously, every series was completed within an hour. Towing speed varied between 2 and 3 knots on a circular course around an anchored buoy. Bathythermograph casts were made either prior to or at the completion of each tow.

Plankton samples were preserved in 10% "buffered" formalin. In the laboratory, each sample was examined, and all penaeid larvae and postlarvae were removed, counted, and identified. Although four genera of shrimp were encountered (*Penaeus*, *Trachypeneus*, *Sicyonia*, and a few *Solencera*), analysis by individual genera was not attempted because of the small sample sizes.

Flow meters in the Clarke-Bumpus samplers were calibrated by the technique of

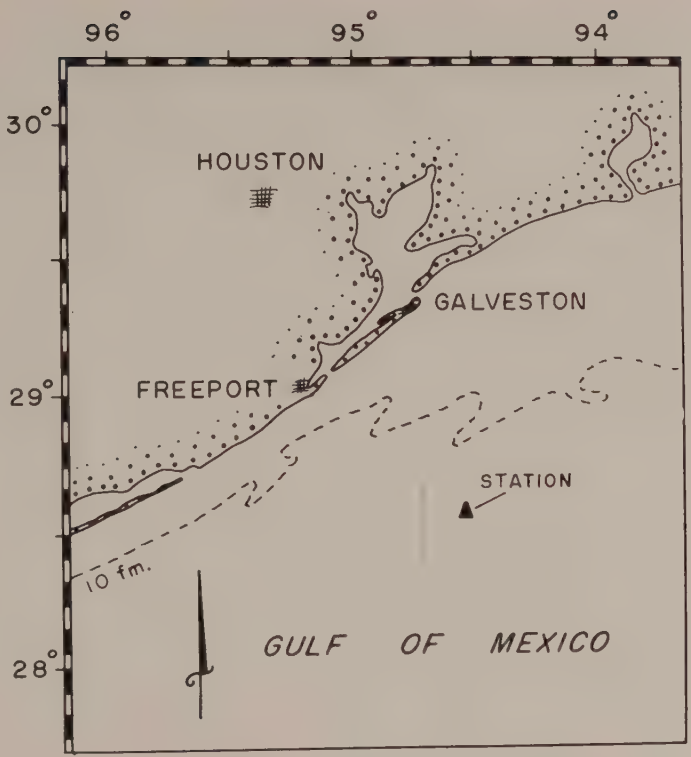

FIG. 1. Station occupied during vertical distribution studies.

Ahlstrom (1948). At speeds varying from 2 to 3 knots, each sampler filtered approximately 10 m^3 of water per 10-minute tow. Catch per tow as reported here consists of numbers per 20 m^3 of water filtered.

Data obtained during each cruise are presented by number, time, and depth of tow in Tables 1–4.

General Depth Distribution

Although the abundance of planktonic stages varied during the June, July, and September cruises, the observed depth distributions of planktonic penaeids were similar (Fig. 3). Data grouped by stages show that immature (planktonic) penaeids were 2 to 4 times more abundant at the 18- and 34-meter depths than at the 2-meter depth. Protozoeal and mysis stages were found frequently in the deeper portions of the water column while postlarval stages occurred most frequently in the upper portion. The observed vertical distribution of the protozoeal and mysis stages agrees with the findings of Russell (1925, 1928) and Heegaard (1953). Russell, who dealt with larvae of several kinds of decapods, found the major concentrations of larvae nearer the bottom than the surface. Heegaard, who reported on larval *P. setiferus*, observed a similar depth distribution. The data presented in Fig. 3 also indicate that the vertical distribution of the planktonic stages is reversed as the shrimp grow from the protozoeal stage to the postlarval

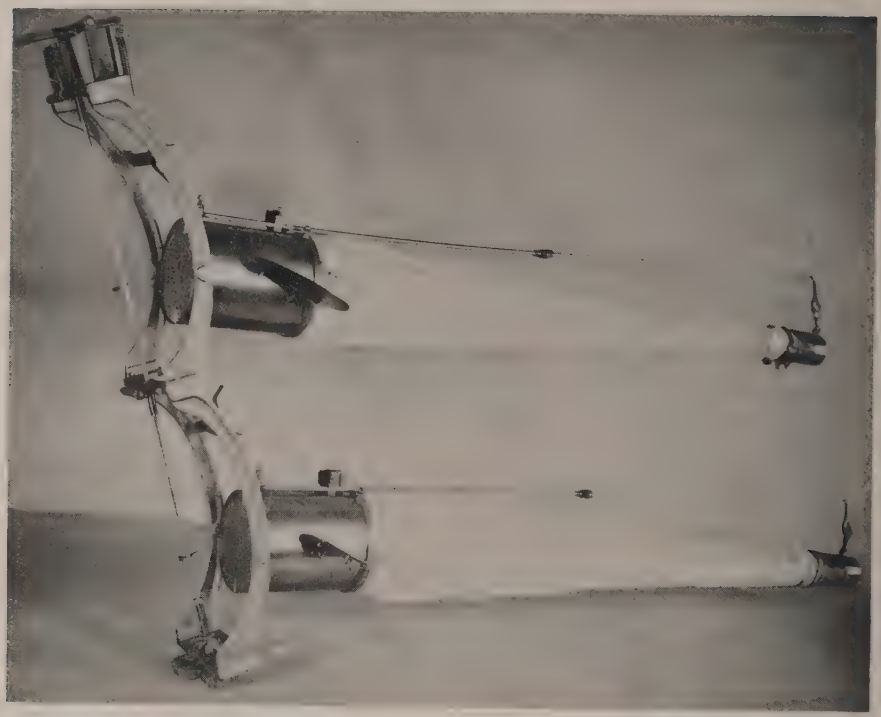

FIG. 2. Clarke-Bumpus sampler used in vertical distribution studies.

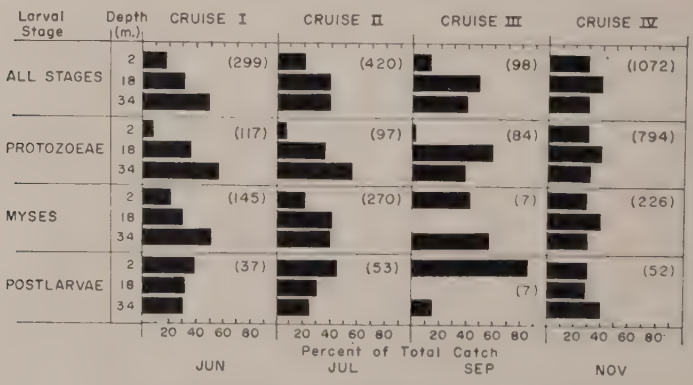

FIG. 3. Depth distribution of immature (planktonic) penaeids.

stage. This reversal is probably related to the animal's increasing mobility permitted by the development of the swimmerets.

The results of the November cruise differed considerably from those of the three previous cruises. Neither the grouped nor the individual-stage data showed any marked differences in depth distribution. Planktonic penaeid forms appeared to be uniformly distributed throughout the water column.

Significance of Temperature

Temperature profiles indicate that a well-defined discontinuity layer was present during the first three cruises, whereas isothermal conditions prevailed within the entire water column in November (Fig. 4). Although measurements of light penetration in the water column were not made, visual observation indicated that the water was extremely clear in June, July, and September but relatively turbid in November. From these observations (temperature profiles and water clarity) it appears that during the first three cruises the water mass was vertically stable with no evidence of vertical mixing, whereas in November it was vertically unstable with vertical mixing. The differences in depth distribution of the planktonic penaeids noted between the first three cruises (June, July and September) and the fourth cruise (November) can be attributed, in part, to the vertical mixing observed in November.

Evidence of Diurnal Migration

Similar short-term changes in the vertical distribution of each planktonic stage were noted in June, July, and September, although the scarcity of planktonic forms and the frequency of non-productive tows make the results of the September cruise of little significance. To illustrate this similarity, the data for each stage were grouped on a 24-hour basis, and average catches were determined for each hour and depth. The results, shown as the percentage of the total hourly catch by depth, are presented in Fig. 5.

These data indicate that various stages of planktonic penaeids do migrate vertically. All stages extended their distribution into the surface layer as darkness descended. The mysis and postlarval stages, however, appeared to migrate at an earlier hour and to remain within the layer longer than did protozoeal stages. These results agree with the

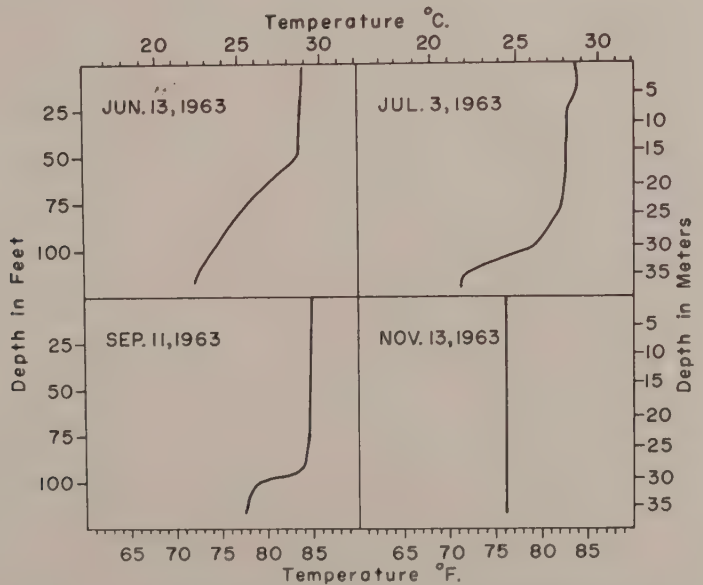

Fig. 4. Temperature profiles at sampling station during vertical distribution studies.

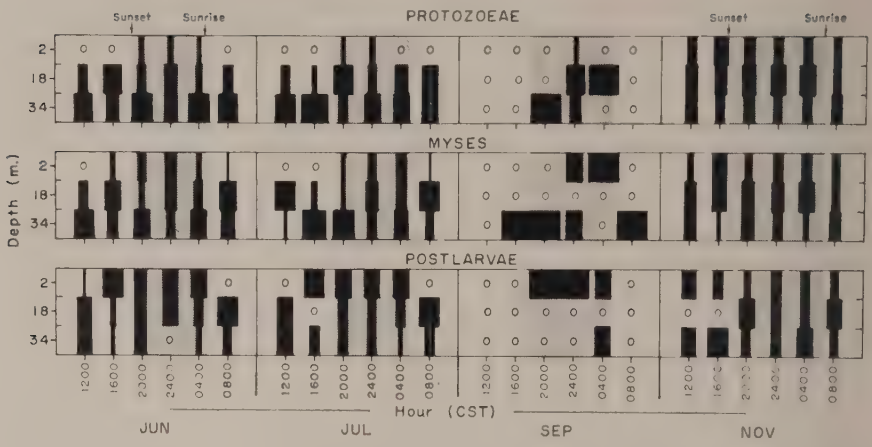

FIG. 5. Variations in the vertical distribution of immature (planktonic) penaeids over a 24-hour period.

findings of Russell (1928) who reported that decapod larvae, in general, extended their distribution into the surface layer with the advent of darkness.

November data gave no evidence of a diurnal migration by any planktonic-stage penaeid. The organisms were, relatively speaking, evenly distributed throughout the water column, probably as a result of the aforementioned vertical mixing.

AVERAGE CATCHES, NIGHT VS. DAY

After all data were grouped by planktonic stage and depth, the average catches during night (2000–0400 CST) and day (0800 1600 CST) were determined for each cruise (Tables 1–4).

TABLE 1

Numbers of planktonic penaeids (per 20 m^3 of water filtered) in each sample, June 12–14, 1963

Planktonic stages	Depth in meters	Hours (CST) 2000	2400	0400	0800	1200	1600	2000	2400	0400	0800	Total no.	Total samples	Per cent of total	No. per tow
All stages	2	14	16	11	2	1	8	6	15	14	2	89	10	16	8.9
	18	13	32	10	16	15	11	22	10	28	29	186	10	34	18.6
	34	45	22	36	14	26	7	37	21	37	31	276	10	50	27.6
	Total	72	70	57	32	42	26	65	46	79	62	551	30	100	18.4
Protozoeae	2	2	3	3	0	0	0	2	6	0	0	16	10	7	1.6
	18	7	19	1	5	5	6	11	5	7	7	73	10	32	7.3
	34	22	14	12	5	9	4	19	14	26	14	139	10	61	13.9
	Total	31	36	16	10	14	10	32	25	33	21	228	30	100	7.6
Myses	2	10	13	4	2	0	1	4	7	8	0	49	10	19	4.9
	18	4	12	9	9	5	3	11	5	16	14	88	10	34	8.8
	34	22	8	23	6	12	2	17	7	11	16	124	10	47	12.4
	Total	36	33	36	17	17	6	32	19	35	30	261	30	100	8.7
Postlarvae	2	2	0	4	0	1	7	0	2	6	2	24	10	39	2.4
	18	2	1	0	2	5	2	0	0	5	8	25	10	40	2.5
	34	1	0	1	3	5	1	1	0	0	1	13	10	21	1.3
	Total	5	1	5	5	11	10	1	2	11	11	62	30	100	2.1

TABLE 2

Numbers of planktonic penaeids (per 20 m^3 of water filtered) in each sample, July 3–5, 1963

Planktonic stages	Depth in meters	Hours (CST) 2000	2400	0400	0800	1200	1600	2000	2400	0400	0800	1200	1600	Total no.	Total samples	Per cent of total	No. per tow
	2	9	10	15	1	0	4	2	24	13	0	0	4	82	12	20	6.8
All stages	18	15	32	22	10	33	9	7	5	13	15	2	1	164	12	39	13.7
	34	8	27	35	9	9	49	7	18	7	0	0	5	174	12	41	14.5
	Total	32	69	72	20	42	62	16	47	33	15	2	10	420	36	100	11.7
	2	1	5	0	0	0	0	0	0	0	0	0	0	6	12	6	0.5
Protozoeae	18	8	9	7	2	0	3	1	0	4	0	1	0	35	12	37	2.9
	34	3	19	11	2	3	13	0	1	1	0	0	3	56	12	57	4.6
	Total	12	33	18	4	3	16	1	1	5	0	1	3	97	36	100	2.7
	2	6	5	13	1	0	0	2	18	7	0	0	0	52	12	19	4.3
Myses	18	7	22	13	8	29	6	3	5	9	9	1	1	113	12	42	9.3
	34	4	7	23	5	3	33	7	16	6	0	0	1	105	12	39	8.7
	Total	17	34	49	14	32	39	12	39	22	9	1	2	270	36	100	7.5
	2	2	0	2	0	0	4	0	6	6	0	0	4	24	12	45	2.0
Postlarvae	18	0	1	2	0	4	0	3	0	0	6	0	0	16	12	30	1.3
	34	1	1	1	2	3	3	0	1	0	0	0	1	13	12	25	1.1
	Total	3	2	5	2	7	7	3	7	6	6	0	5	53	36	100	1.5

TABLE 3

Numbers of planktonic penaeids (per 20 m^3 of water filtered) in each sample, September 10–12, 1963

Planktonic stages	Depth in meters	Hours (CST) 2000	2400	0400	0800	1200	1600	2000	2400	0400	0800	1200	1600	Total no.	Total samples	Per cent of total	No. per tow
	2	1	4	2	0	0	0	2	1	1	0	0	0	11	12	11	0.9
All stages	18	0	47	1	0	0	0	0	1	0	0	0	0	49	12	50	4.1
	34	4	29	0	1	0	0	2	0	1	0	0	1	38	12	39	3.2
	Total	5	80	3	1	0	0	4	2	2	0	0	1	98	36	100	2.7
Protozoeae	2	20	24	16	24	24	26	26	12	18	26	23	12	251	12	32	20.9
	18	0	47	1	0	0	0	0	1	0	0	0	0	49	12	58	4.1
	34	3	28	0	0	0	0	2	0	0	0	0	0	33	12	39	2.8
	Total	3	77	1	0	0	0	2	1	0	0	0	0	84	36	100	2.3
Myses	2	0	1	2	0	0	0	0	0	0	0	0	0	3	12	43	0.2
	18	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0.0
	34	1	1	0	1	0	0	0	0	0	0	0	1	4	12	57	0.3
	Total	1	2	2	1	0	0	0	0	0	0	0	1	7	36	100	0.2
Postlarvae	2	1	1	0	0	0	0	2	1	1	0	0	0	6	12	86	0.5
	18	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0.0
	34	0	0	0	0	0	0	0	0	1	0	0	0	1	12	14	0.1
	Total	1	1	0	0	0	0	2	1	2	0	0	0	7	36	100	0.2

The night-day catch ratios in June, July, and September were 1.6, 1.9 and 53.0 respectively. The comparatively large difference between September's average night and day catches, which yielded a high night-day catch ratio, was believed due to the sporadic occurrence and low density of penaeids in that month, not necessarily any inadequacy of the sampling technique. Larval abundance, as indicated from the results presented in Table 5, was considerably lower in September than during any of the other months. Consequently the variation in numbers of larvae between tows appeared more pronounced and resulted in seemingly biased data. The timing of this cruise apparently did not coincide with the second period of increased abundance of larvae which was expected

TABLE 4

Numbers of planktonic penaeids (per 20 m^3 of water filtered) in each sample, November 12–14, 1963

Planktonic stages	Depth in meters	Hours (CST) 2000	2400	0400	0800	1200	1600	2000	2400	0400	0800	1200	1600	Total no.	Total samples	Per cent of total	No. per tow
All stages	2	28	38	22	31	29	35	29	13	29	33	30	16	333	12	31	27.8
	18	48	46	49	21	20	23	27	19	34	38	51	48	424	12	40	35.3
	34	34	15	21	16	31	20	32	23	19	51	37	16	315	12	29	26.2
	Total	110	99	92	68	80	78	88	55	82	122	118	80	1,072	36	100	29.8
Protozoeae	2	0	2	0	0	0	0	0	0	0	0	0	0	2	12	3	0.2
	18	36	34	38	16	16	14	18	15	24	28	38	42	319	12	40	26.6
	34	24	11	15	14	21	14	20	12	14	39	28	12	224	12	28	18.7
	Total	80	69	69	54	61	54	64	39	56	93	89	66	794	36	100	22.1
Myses	2	5	10	5	6	4	8	3	0	11	5	6	3	66	12	29	5.5
	18	10	9	9	4	4	9	7	2	10	7	13	6	90	12	40	7.5
	34	8	2	3	2	10	4	9	9	4	11	8	0	70	12	31	5.8
	Total	23	21	17	12	18	21	19	11	25	23	27	9	226	36	100	6.3
Postlarvae	2	3	4	1	1	1	1	0	1	0	2	1	1	16	12	31	1.3
	18	2	3	2	1	0	0	2	2	0	3	0	0	15	12	29	1.3
	34	2	2	3	0	0	2	3	2	1	1	1	4	21	12	40	1.8
	Total	7	9	6	2	1	3	5	5	1	6	2	5	52	36	100	1.4

TABLE 5

Average number in night and day samples, all stages and depths combined by cruise

Period	Cruise I June	Cruise II July	Cruise III September	Cruise IV November
Night	22	15	5	29
Day	14	8	<1	30

on the basis of evidence from the synoptic plankton work conducted by laboratory personnel in 1961 and 1962. The night-day catch ratio was 1.0 in November.

Student's "t" test, applied to the mean values for the night and day catches, revealed significant differences at the 95% level during June and July but not in November. Due to the small sample sizes, tests were not made to compare the average night and day catches for either the individual stages or for the September data.

Summary

1. Four research cruises, one each in June, July, September, and November 1963, provided information on the vertical distribution of planktonic-stage penaeids at a 37-meter station in the northwestern Gulf of Mexico, 50 miles south of Galveston, Texas. On each occasion, samples were obtained with a Clark-Bumpus sampler towed at three depths (2, 18, and 34 meters) every four hours over a period of two consecutive days. Tows lasted ten minutes and were made on a circular course around a buoy anchored in about 37 meters of water.

2. In June, July, and September, the data grouped over all stages indicated that planktonic penaeids were most frequent at and below mid-depth (18 meters). Protozoeal stages occurred most frequently near the bottom and postlarval stages at or above mid-depth. This observation suggests that as larval development progresses, the depth of greatest

abundance decreases. In November, planktonic-stage penaeids were more or less uniformly distributed throughout the water column due to the "fall overturn."

3. Temperature profiles and visual observations of water clarity indicated that the water mass was vertically stable during the first three cruises, whereas it appeared to be vertically unstable in November. These seasonal differences in water conditions probably accounted for the change in vertical distribution of planktonic penaeids noted during the November cruise.

4. Each planktonic stage extended its distribution into the surface layer either just prior to or after the onset of darkness.

5. Statistical tests of average night and day catches (all stages and depths combined) in June, July, and November revealed significant differences in June and July but not in November. Average catches in June and July were approximately two times greater at night than during the day.

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Reprinted from

SCIENCE IN ALASKA

1964

Proceedings Fifteenth Alaskan Science Conference College, Alaska

August 31 to September 4, 1964

Edited by George Dahlgren

Published by
ALASKA DIVISION
AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

March 15, 1965

EFFECTS OF THE ALASKA EARTHQUAKE ON PINK AND CHUM SALMON RUNS IN PRINCE WILLIAM SOUND

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The earthquake that struck Alaska March 27, 1964, centered in northwestern Prince William Sound and produced drastic environmental changes in the spawning habitat of pink (Oncorhynchus gorbuscha) and chum (O. keta) salmon runs homing to streams of that area. Its total impact cannot be measured until spring, 1965 when the survival of salmon eggs deposited in uplifted or downwarped stream areas in 1964 can be determined. In this report, some results of pre-earthquake ecological studies on a Prince William Sound stream are presented, and their implications regarding future abundance of pink salmon in view of the earthquake-produced changes in spawning habitat are discussed.

Since 1960 runs of pink salmon in Prince William Sound have ranged in magnitude from 3.2 to 8.7 million fish and those of chum salmon from 0.6 to 1.4 million fish (1). Spawning surveys by the Fisheries Research Institute, University of Washington, and the Alaska Department of Fish and Game (2) demon-

strated that from 35 to 76% of all pink salmon spawning and a substantial portion of chum spawning occurs in intertidal stream beds which were drastically changed by the earthquake. Uplift ranging from eight feet at the northeastern end of Montague Island to 34 feet at the southwestern end and from two to eight feet along the eastern shore of the Sound has removed stream areas from tidal influence. Subsidence to a maximum of six feet along the western shore has drowned old intertidal areas. There was little or no change in land levels in the northcentral area. The future abundance of pink and chum salmon population is dependent on their ability to utilize and adapt to changed environments in both old and new intertidal zones.

Ecology of Intertidal Stream Bed

Studies of intertidal spawning under way since 1960 at the Bureau of Commercial Fisheries Field Research Station at Olsen Bay provide a basis for evaluating the earthquake-produced changes in stream elevations. The station is located on the east side of Prince William Sound in Port Gravina in an area that was uplifted five feet. Research there has been based on the theory that intertidal spawners (as opposed to salmon spawning in fresh water) are a discrete population. Evidence to support this theory is provided by: (a) difference in time of spawning--spawning in intertidal areas tends to persist later than spawning in upstream areas above tidal influence; (b) cyclic abundance of intertidal spawning--salmon utilizing the intertidal zone form the largest portion of the total spawning population on even-numbered years (2); (c) contrasting environment of the fresh water and intertidal stream bed--at the depths eggs are deposited in the intertidal stream bed significant changes in temperature, salinity, and dissolved oxygen of the intragravel water occur with each rise and fall of the tide. There is, of course, considerable variability in the freshwater intragravel water temperature and dissolved oxygen, but they are essentially controlled by rainfall and solar radiation. Tide cover over the intertidal stream bed provides greater and cyclic variability in these factors.

At Olsen Bay the mean high tide is 11.8 feet. The 12-foot tide level is the arbitrary separation point between intertidal and freshwater spawning in the studies at Olsen Bay. Each foot of elevation proceeding upstream from the zero tide level is covered by salt water for progressively less time, and the magnitude and duration of shifts in temperature, dissolved oxygen, and salinity are less. The 3-foot level is covered by salt water

about 80% of the time, the 6-foot level about 50% of the time, and the 12-foot level less than 5% of the time (Fig. 1). Changes in temperature at the depth eggs are deposited (approximately six to eight inches in the stream bed) are directly dependent on the depth of the salt water and reach a maximum at high tide (Fig. 2). Figure 2 shows a temperature jump of 6°C. with the high tide at the 7-foot tide level. At the 11- and 12-foot tide levels temperature may rise 1° to 3° C., and at the 4-foot level it may rise as much as 9° C. Salmon eggs incubating in the intertidal stream bed receive about 25% more heat than do those incubating in the freshwater stream bed. Salinity also increases with the rising tide (Fig. 3). For example, in a redd at the 7-foot tide level salinity increased 8°/oo. There is a constant residual salinity from this area downstream of about 3°/oo. Salinities up to 25°/oo have been observed at all levels in the intertidal zone. Saline water is leached from the stream bed gravels in the upper intertidal areas by flowing fresh water as the tide falls. Shifts in the dissolved oxygen content of intergravel waters occur with the rising tide; the amount of change is variable from point to point, depending upon permeability of the stream bed. In a redd at the 7-foot tide level a lowering in dissolved oxygen content of 2.5 mg/l has been observed (Fig. 4). At other points, particularly in the upper intertidal levels, there is little or no change.

Tide water over the intertidal stream bed acts as a settling basin for fine materials, both organic and inorganic, carried downstream. The presence of fine materials, here defined as particles passing through an 0.833-mm standard soil sieve, influences the quality of the spawning bed. McNeil and Ahnell (4) have demonstrated an inverse relation between permeability of bottom materials and the fraction of fine particles constituting the total volume of the stream bed. The rate of permeability influences the delivery of oxygen to developing eggs and alevins and the removal of toxic metabolites. McNeil and Ahnell also demonstrated that the rate of permeability dropped sharply when the volume of fine materials exceeded 12.7% of the total. They compared the magnitude of pink salmon runs with stream bed composition in six southeastern Alaska streams and found that in streams with spawning beds containing 15% or more by volume of fine material, the runs were small and marginal. In 1962 samples of the intertidal stream bed in three sections of Olsen Creek were taken to describe average bottom composition in each. The percentage by volume of fines in each section was as follows: upper intertidal zone (between tide levels 9 1/2 and 11 feet), 8.5%; midintertidal (between tide levels 5 1/2 and 9 feet),

Fig. 1 Percent of time different tide levels in Olsen Creek are covered with tide water (3).

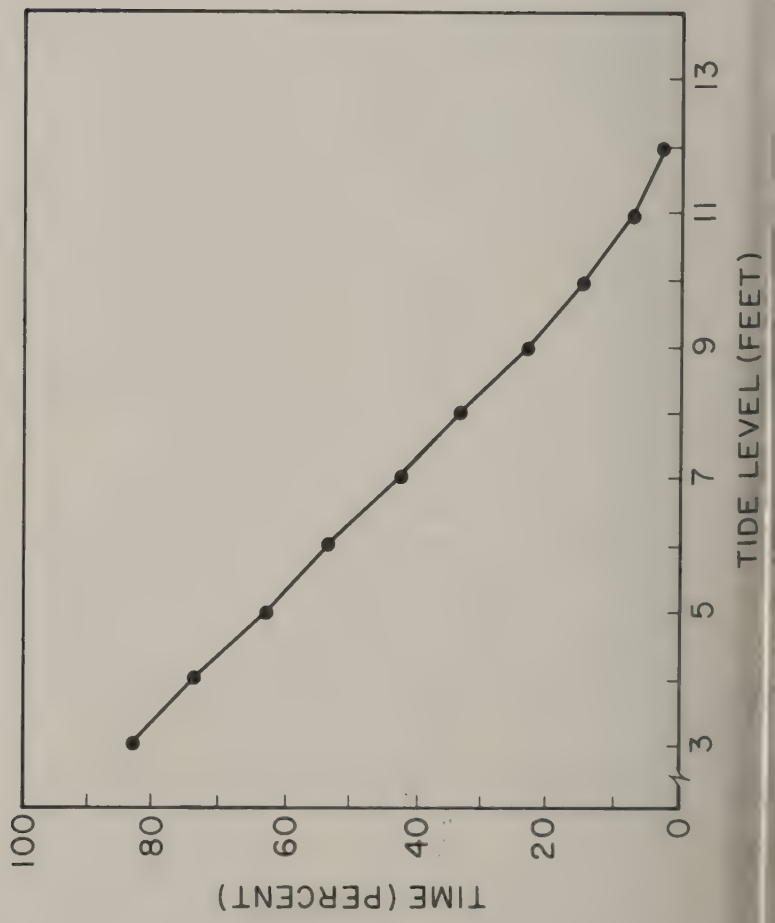


Fig. 2 Tide-associated changes in temperature in a mid-intertidal zone redd--Olsen Creek.

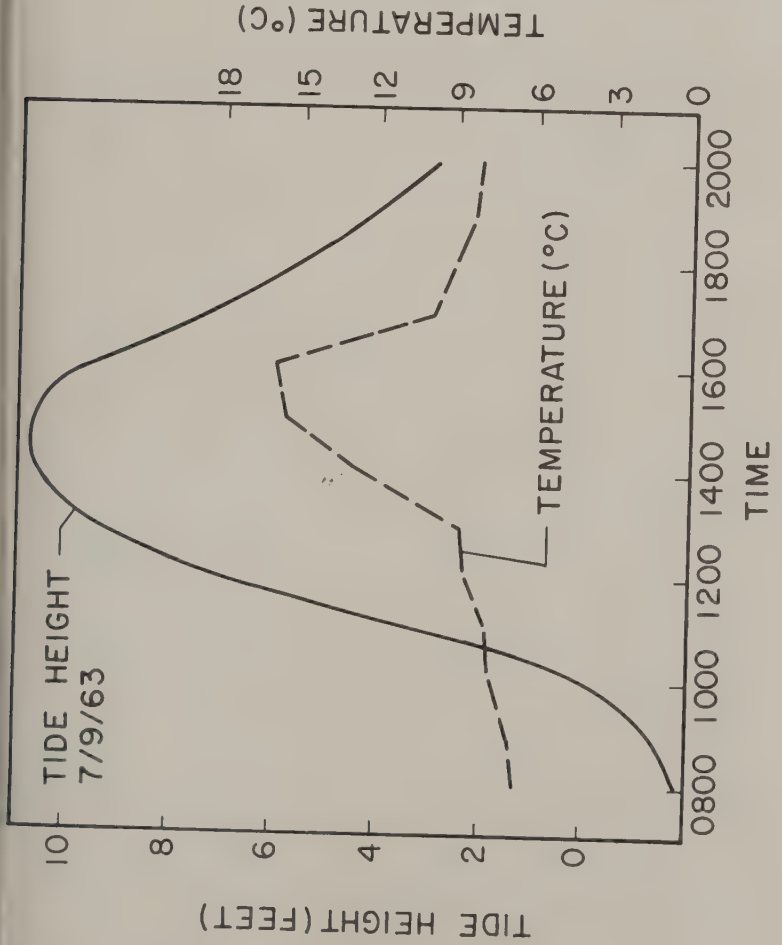
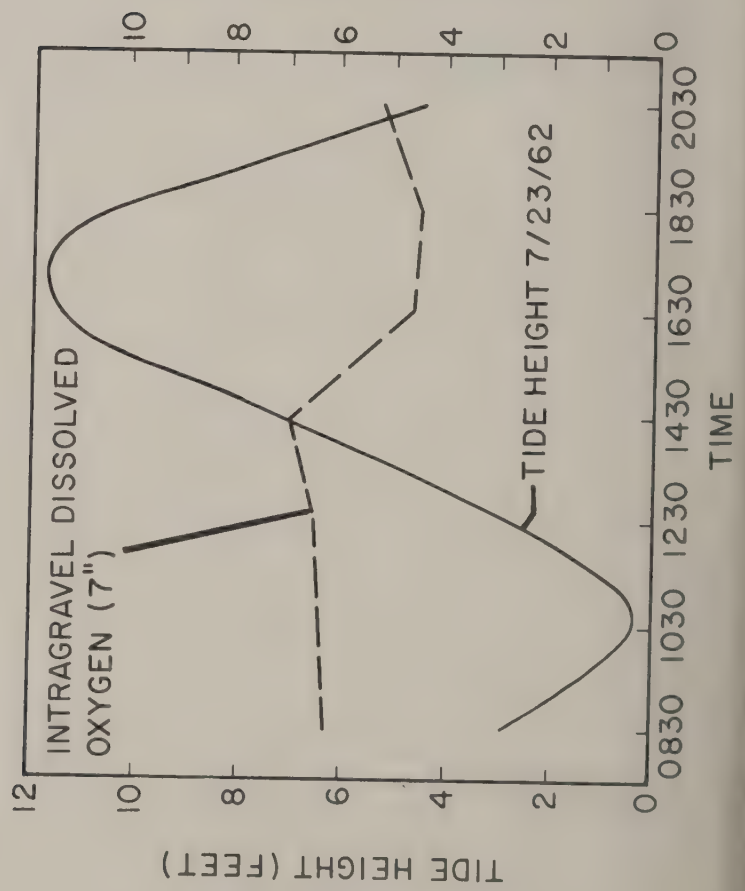


Fig. 4 Tide-associated changes in dissolved oxygen in a midintertidal zone redd--Olsen Creek.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0 2 4 6 8 10 12

9.9%; and the lower intertidal (between tide levels 2 1/2 and 5 1/2), 13.5%.

To determine productivity at different elevations of the intertidal stream bed, the three sections are sampled routinely each year for total egg deposition and winter survival. Sampling takes place in October after the end of spawning and again in March just before the downstream fry migration. The sampling method has been described by McNeil (5). Briefly, it consists of flushing eggs from randomly chosen plots 0.1 m^2 in area by pumping a mixture of water and air into the stream bed. Eggs are captured by means of a net attached to the metal frame that defines the area. The data collected are expanded to show stream bed utilization as the average number of eggs found per square meter of stream bottom (Fig. 5).

Pink salmon spawned most heavily in the midintertidal section in 1962 and1963. In the lower intertidal area 930 eggs per square meter were deposited in 1962; in 1963 only two eggs per square meter were deposited here. We believe that spawning occurred in the lower section in 1962 as a result of crowding--an estimated 103,000 pink salmon and approximately 8,000 chum salmon spawned in the intertidal area in 1962, whereas in 1963 an estimated 60,000 pink salmon and 5,000 chum salmon spawned in the intertidal zone. The difference in occupancy of the lower intertidal area between the two years suggests that pink salmon would not ordinarily select this area for spawning and do so only under the pressure of high spawning population densities. Chum salmon appear more specific in their requirements of a spawning bed; most chum salmon spawning occurs in the upper and midintertidal sections but rarely in the lower section. Winter survival of eggs deposited in these sections follows a different pattern; it is highest in the upper intertidal area and becomes progressively less downstream (Fig. 6). On the basis of these two years of observation we anticipate pink salmon winter survival rates of 15 to 33% in the upper intertidal zone, 8 to 12% in the midintertidal zone, and 3% or less in the lower intertidal zone, depending on the degree to which this area is utilized. For chum salmon we expect survival to be from 40 to 50% in the upper area and 10 to 15% in the middle section. No utilization is expected in the lower section.

Fig. 5 Egg deposition in sections of the intertidal stream bed--Olsen Creek.

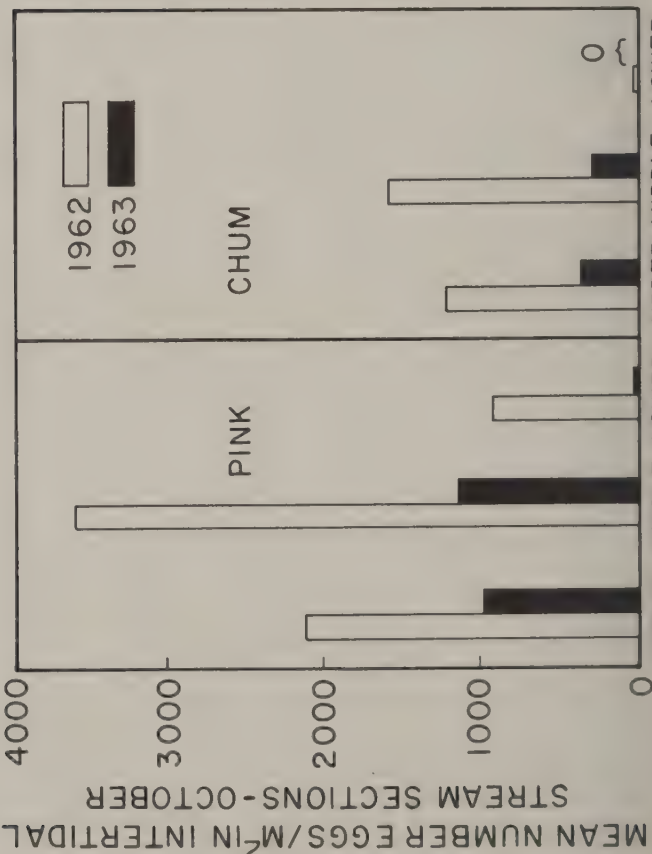
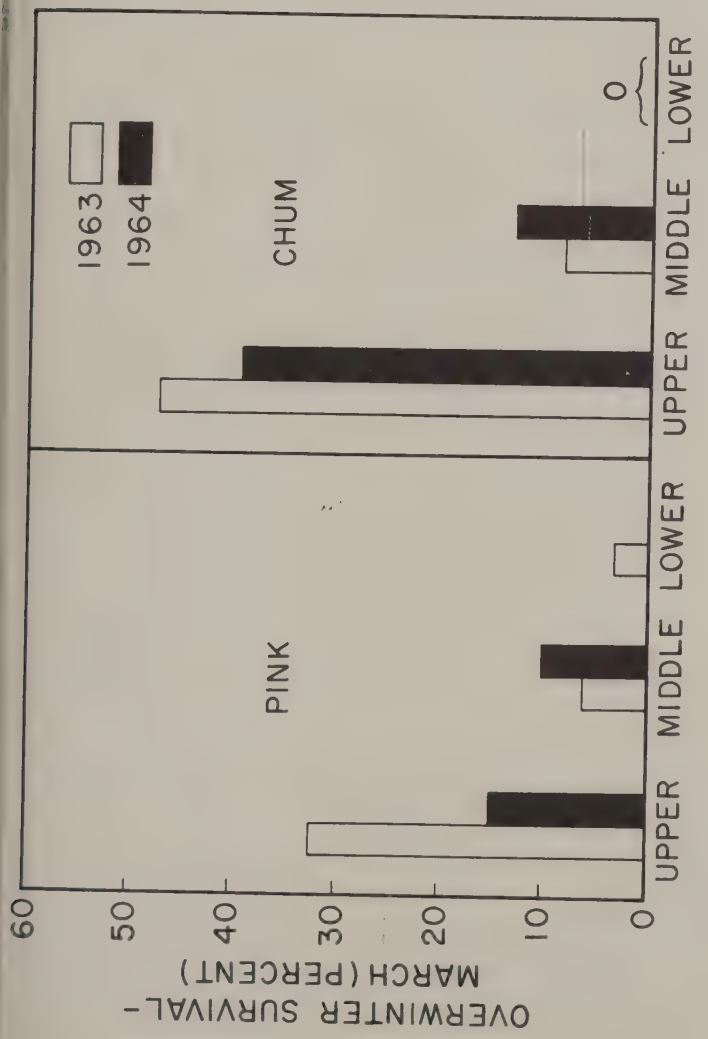


Fig. 6 Winter survival in sections of the intertidal stream bed--Olsen Creek.



Effects of the Earthquake on Future Abundance of Pink and Chum Salmon

The potential impact of the earthquake can be appraised by the fraction of the total population that normally spawns in the intertidal zones of streams in uplifted and downwarped areas. There are 350 streams bordering Prince William Sound that are used by salmon. The Alaska Department of Fish and Game classifies these streams as "major" or "minor" according to the size of the escapement. There are 110 major streams, which have average escapements of 5,000 or more salmon, and 240 minor streams, which have average runs of fewer than 5,000. Twenty-seven streams, 12 major and 15 minor, are located in areas downwarped from two to six feet. On the average, 15% of the total Prince William Sound pink salmon escapement and 25% of the chum salmon spawning occurs in these 27 streams. In uplifted areas there are 199 streams, 43 major and 156 minor, which, on the average, obtain 60% of the total pink salmon and 65% of the chum salmon escapement (6). The percentage of pink salmon utilizing intertidal zones of Prince William Sound between 1952 and 1961 is given in Table 1. On odd-numbered years an average of 46% of all spawning occurred in intertidal zones; in even-numbered years an average of 74% occurred. The potential impact of the earthquake is brought

Table 1. Percentage of pink salmon spawners utilizing intertidal zones of Prince William Sound, 1952-61 (2)

Year	No. of Streams Observed	No. of Spawners Observed*	Percentage of Spawners in Intertidal Zone
1952	69	111,000	72
1953	65	177,000	43
1954	80	658,000	72
1955	84	282,000	54
1956	84	660,000	75
1957	156	83,000	43
1958	186	584,000	76
1959	20	135,000	57
1960	192	896,000	77
1961	221	1,508,000	35

*Includes only that portion of escapement count committed to specific stream sections.

into clear perspective by the fact that the intertidal zones of 226 of the 350 Prince William Sound salmon streams have been altered--the habitats of 56% of the total pink salmon spawning population on even-numbered years and 33% in odd-numbered years.

Earthquake-caused changes in stream environment have produced both immediate and long-term adverse effects on the abundance of pink and chum salmon in Prince William Sound. The earthquake occurred just before the beginning of the downstream salmon fry migration, which takes place from mid-April to mid-June. Its immediate effects were more apparent as they were readily observable. As an aid to predicting the magnitude of the 1965 pink salmon run, Alaska Department of Fish and Game biologists conducted a fry sampling program in 29 streams between April 1 and 18, 1964, to establish pink salmon abundance. In riffle areas of some streams they found that a seismic wave deposited an overburden of mud and silt that caused mortalities by suffocation as great as 70%. The total fry loss by this cause is unknown. Wave-incurred fry losses occurred in other streams because of scouring and gravel shift (6). In new intertidal zones in the downwarped area on the western side of Prince William Sound, the effect of sudden new stresses introduced to pre-emergent fry by diurnal changes in temperature, salinity, and dissolved oxygen content of the intragravel water is unknown.

If Olsen Creek is representative of streams in uplifted areas where no damage from seismic waves occurred, then fry losses in streams in like situations were insignificant. We sampled the Olsen Creek intertidal stream bed during the first week of March, 1964 to determine the abundance of pre-emergent pink and chum salmon fry, and from this we could estimate winter mortality. We resampled the area again in April, two weeks after the earthquake, and found the number of pre-emergent fry unchanged. We observed no dead or deformed fry which could be attributed to the earthquake.

Even though damage did not occur in all streams, it is clear that the earthquake caused the death of a large number of pre-emergent fry and that runs returning from the 1963 brood year will be smaller than they would have been had the earthquake not occurred. It is doubtful that the total loss from this cause can be ascertained because of the following reasons: (a) A correlation between the size of pink salmon escapement and its return two years later in Prince William Sound exists,

but the variability in this generation-to-generation relation can be great enough to mask any earthquake-produced losses. (b) Mortality to successfully deposited eggs that occurred prior to the earthquake is unknown.

The long-term effects of the earthquake, which will be measured by the survival of eggs deposited by the pink salmon runs of 1964 and 1965, are intangible. To a large extent the future abundance of pink and chum salmon will depend on their ability to adapt to the new situations. At this time, I only can list critical questions which can be answered only after the next two years have passed:

(1) Along the western shore of Prince William Sound subsidence has shortened streams by drowning old intertidal zones. The new intertidal areas should be productive, but the amount of freshwater stream bed has been reduced. This can limit future abundance in two ways--by the loss of available freshwater spawning space and by causing spawning to occur in undesirable areas where natural survival is low. The question is: Will spawning space now available in the downwarped areas support runs at the level existing before the earthquake? (Streams in uplifted areas were lengthened, and it is possible that the newly exposed areas might offset losses of stream space due to downwarp.)

(2) Stream bed permeability is partly determined by particle compaction, arrangement, and size. A secondary effect of the earthquake was compaction of alluvial conglomerates. An extreme example of this occurred in a stream located at the head of Pigot Bay in northwestern Prince William Sound. A U. S. Geological Survey team measured downwarp of the bedrock in this area at minus three feet; by comparing present tide levels with those existing before the earthquake, we have measured subsidence of the stream bed at minus six feet or twice that of bedrock. Compaction of spawning grounds must have occurred to some degree in all streams of the area. The question is: Will stream action and the digging activity of salmon as they prepare their redds loosen bottom materials enough to provide a spawning bed of suitable quality?

(3) The present distribution of pink and chum salmon spawning in Prince William Sound streams poses several serious questions. At Olsen Creek, for instance, before the earthquake 95% of the chum salmon and 75% of the pink salmon spawners utilized the intertidal area. The chum salmon run

there this year--estimated at 5,000--is completed, and only 25% of it spawned in the intertidal area. Pink salmon still are entering the stream, but at present only 35% of the run is spawning in this zone. Chum salmon have utilized the intertidal area down to the present 7-foot tide level, and the pink salmon are spawning to the present 6-foot level. Our pre-earthquake lower intertidal study section was located between elevations 2.5 and 5.5 feet. Now, because of uplift, this area corresponds to the present 7.5- to 10.5-foot level. The present elevations in this section provide an intertidal environment roughly corresponding to our old midintertidal zone (elevations 5.5 to 9 feet) in which winter survival ranged from 8 to 15%. This is an area never before occupied by chum salmon and used by pink salmon only under duress of population pressure. Before the earthquake this was a fallout zone for fine materials carried downstream and presented a marginal, poor quality spawning bed because of the high volume of fines (13.5% by volume) and because of the extreme changes in temperature, salinity, and dissolved oxygen, which were due to its low elevation. The several questions posed by the changed distribution of spawners are: (a) Will stream action and digging activities of spawning salmon wash out fine materials soon enough to permit survival rates equivalent to pre-earthquake levels in newly uplifted areas? (b) Is survival of eggs deposited in freshwater areas by the fraction of spawners formerly using the intertidal area linked to the intertidal environment? (c) If these eggs do survive in a freshwater environment, will the lack of heat provided by tidal cover (which is a major factor in the growth of eggs and alevins) delay their normal time of downstream migration and hence apply a new stress to this segment of the run?

Failure to surmount these critical points can result in a severe reduction to either or both the freshwater and intertidal spawning populations.

The earthquake has provided us with an unparalleled experimental situation. From it we hope to prove or disprove the hypothesis of discrete intertidal spawning populations and to learn the degree to which pink and chum salmon can adapt to abrupt, severe environmental change.

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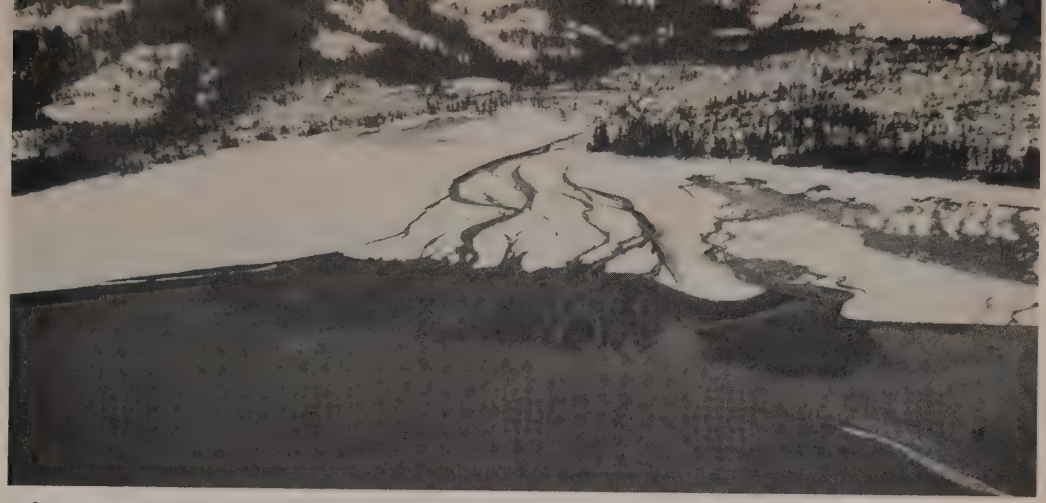

Relocation of the intertidal zone and stream bed instability are shown in this photograph taken of Quadra Creek on November 1, 1964. Present high-tide line indicated by snow line was under permanent salt water before the earthquake. The cutbanks and braided channels in the newly uplifted beach surface are evidence of stream bed instability and channel changes yet to occur.

Aftermaths of the Alaska Earthquake In Prince William Sound

By Fredrik V. Thorsteinson

• Changes in stream elevations resuting from the March 27, 1964, Alaska earthquake produced drastic alterations in the physical environment of Prince William Sound Pink salmon spawning grounds. The U. S. Bureau of Commercial Fisheries Auke Bay Laboratory has just completed a study of the initial effects of the earthquake on spawning streams in the sound, and the results are disturbing. The most important spawning areas of Prince William Sound—the intertidal streambeds—have been directly and adversely affected by the changes in land elevation and subsequent secondary effects. George Plafker of the Alaskan Geology Branch, U. S. Geological Survey, has found that Montague Island was uplifted 8 feet at its northeastern end and 34 feet at its southwestern end and that uplift of the land mass along the eastern shore and adjacent islands ranged from 1 to 8 feet. Land areas along the western and northwestern shore subsided 1 to 6 feet, but in the north-central area little or no changes have been noted.

Mr. Thorsteinson is a Fishery Research Biologist with the U. S. Bureau of Commercial Fisheries Biological Laboratory at Auke Bay, Alaska.

• Spawning surveys by the Fisheries Research Institute and the Alaska Department of Fish and Game have demonstrated that an average of 46 percent of the total Prince William Sound Pink salmon run spawns in the intertidal stream channel in odd-numbered years and an average of 74 percent in even-numbered years. The potential impact of the earthquake can be understood from estimates of the population that normally spawns in the intertidal zones of streams in uplifted and downwarped areas. Elevations of 226 streams used by about 75 percent of the total Pink salmon population have been changed. Therefore, it is possible that the spawning habitats of about 37 percent of the odd year—and 56 percent of the even-year Pink salmon runs have been altered by the earthquake or its secondary effects.

• Intertidal studies underway since 1960 at the Bureau of Commercial Fisheries Research Station at Olsen Bay, which is located in an area that was uplifted 5 feet, provide a basis for evaluating changes in stream elevations. To augment studies on the effects of the earthquake at Olsen Creek, additional studies were made at the end of the spawning season in sections of present and former intertidal streambeds of three additional streams: Wild Creek (Port Chalmers, Montague Island), uplifted 10 feet; O'Brien Creek (Crab Bay, Evans Island), uplifted 10 feet; and Swanson Creek (Pigot Bay, northwest mainland), downwarped 6 feet.

• In intertidal stream channels, Pink salmon usually spawn above the 4-foot tide level, with greatest concentrations of spawners occurring in the upper intertidal areas. Survival of eggs deposited in intertidal streambeds is usually highest in the upper intertidal zones and becomes progressively less downstream. Nearly all eggs deposited below the 5-foot tide level die before hatching. High mortality rates below the 5-foot level of a stream are attributed to adverse temperature, salinity, and dissolved oxygen relationships caused by changing tides and to the low rate of subsurface flow or permeability of the streambed. The amount of fine materials present in a streambed influences rates of permeability which in turn influence the delivery of oxygen to developing

eggs and embryos and also the removal of toxic metabolites. Tidewater covering an intertidal stream channel acts as a setting basin for fine organic and inorganic materials carried downstream, and consequently the amount of fine material and silt in the streambed is greater in the lower intertidal zone than in other sections of the stream.

• The distribution of Pink salmon spawning in intertidal areas in 1964 was similar to that observed in previous years at the same tide levels. Despite uplift or subsidence of stream areas, Pink salmon behavior was normal in regard to intertidal utilization. Spawners did not "home" to former intertide areas of uplifted streams — now freshwater areas — which had been used by previous generations for spawning. The returning adults instead chose the newly formed intertidal zone. At Olsen Creek, the proportion of intertidal to freshwater spawners was about average—70 to 30 percent, but intertidal spawning occurred farther downstream than in previous years. About one-third of the eggs deposited in the intertidal streambed by spawning Pink salmon were deposited below the present 9-foot tide level (former 4-foot level) in an area never before utilized. Subsidence has drowned former intertidal areas of some streams, and as a result, spawners moved upstream to productive tide levels. For example, in the spring of 1958 and 1959, we found 60 and 120 live Pink salmon fry per square meter of intertidal streambed in the former 8- to 12-foot section (present 2- to 6-foot section) of Swanson Creek. This fall we found only four salmon eggs per square meter in the same area. Subsidence has the net effect of shortening streams and removing the lower stream areas from production.

• The persistent behavior of Pink salmon in selecting intertidal stream channels will lead to greater than usual mortality to successfully deposited eggs. Two factors producing mortalities that are a direct consequence of the earthquake are already apparent in streams in uplifted areas: (1) Uplift has raised former low intertidal streambeds to levels that should be productive. Before the earthquake these areas were not used, or, if used, they were unproductive because of the high percentage of fine materials and silt and the resulting low rates of permeability. Stream action and digging activities of spawning salmon have not yet cleared all streams of silt. For example, the O'Brien Creek intertidal streambed still contains a large amount of silt and organic debris. Spawning in the creek was moderately heavy between the present 9½-foot and 11-foot tide levels and produced an average deposition of 163 Pink salmon eggs per 0.1 square meter, but only 42 percent of these eggs remained alive at the end of spawning.

Survival was twice as great in comparable areas of Olsen and Wild Creeks where the streambed was relatively clean. (2) Streams in uplifted areas have not yet reached equilibrium. They are degrading or cutting down and moving laterally as they seek sea level. During floods, new channels are formed by dissection of uplifted beach surfaces. In all three of the uplifted streams studied there is evidence of lateral shifting or new channel formation or both. Olsen Creek changed channels twice during the summer at the 4- and 6-foot tide levels, but changes occurred before spawning. A new channel was formed in the former upper intertidal zone of Wild Creek during an early September flood while spawning was still in progress. The number of eggs lost from this cause is unknown, but we found only one-fourth as many eggs there as in comparable sections of other streams sampled. This stream is also shifting laterally in a southwest direction along the length of its new intertidal zone.

O'Brien Creek split into two channels at the 11-foot tide during a mid September flood. Flow is concentrated in the new channel, and at present it appears to be the more permanent of the two.

The relocation of the intertidal zone and the stream bed instability caused by uplift are graphically illustrated by a November 1, 1964, aerial photograph of Quadra Creek. This major stream, located in Hanning Bay, Montague Island, is in an area uplifted 25 feet. The present intertidal zone, defined by a 4½-foot tide when the picture was taken and the snowline left by the previous high tide of 12.1 feet, was under permanent saltwater cover before the earthquake. The former intertidal stream channel was in the vicinity of the tree line. The cutbanks and braided channels in the newly uplifted beach surface are evidence of streambed instability and channel changes yet to occur. There is danger that many eggs or preemergent fry will be left stranded in abandoned channels during fall and spring floods or will be dislodged from the streambed during the process of degradation.

A secondary effect of the earthquake which may be harmful to developing eggs and embryos in all streams of the area is compaction of the spawning beds. Stream bed permeability is partly determined by particle compaction, arrangement, and size. Plafker measured downwarp of bedrock at Pigot Bay at between 4 and 5 feet. By comparing present tide levels with those before the earthquake, we have measured subsidence of the streambed at minus 6 feet or about 1.5 feet more than that of adjacent bedrock. Compaction of the spawning beds must have occurred to some degree in all streams of the area.

• The total impact of the earthquake on abundance of Prince William Sound Pink salmon will be first measured in the spring of 1965.

It is evident now, however, that the runs returning from the 1964 and perhaps the 1965 brood years will not be as large as they would have been had the earthquake not occurred. Since a major portion of Prince William Sound streams are located in uplifted areas, egg and fry mortalities are certain to be higher than average until (1) the degrading process is complete and streams have stabilized and (2) stream action and digging activity of spawning salmon remove fine materials from newly exposed spawning beds.

• On the encouraging side—there have been earlier major changes in land levels in Prince William Sound, and the salmon runs have persisted. Fredrica deLaguna, a University of Washington anthropologist, in her report on the archaeology of Prince William Sound issued in 1956 cites Captain Vancouver's observations made while he was anchored in Port Chalmers during May and June of 1794: ". . . stumps of trees, with their roots still fast in the ground were also found in an advanced state of decay nearly as low down as the low water of spring tides." Evidence of this subsidence, or perhaps a more recent one, is shown by stumps still standing on the bare beach along Wild Creek. She also found reference to changes in landmass elevations in a 1910 Geological Survey Bulletin by Grant and Higgins. These authors found evidence that the land between Simpson and Sheep Bays has sunk at least 4 feet and that subsidence of 10 feet occurred in Port Gravina.

If all or most earthquake-affected streams in Prince William Sound display characteristics shown in the four streams we have under close observation, a temporary reduction in abundance of future pink salmon runs will occur. The runs should return to pre-earthquake levels as the streams stabilize and the salmon adjust to their new spawning habitats.

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BACTERIAL EPIZOOTICS IN LARVAL AND JUVENILE PELECYPODS.

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(Abstract)

Advances in methods for induced spawning of bivalve mollusks and for algal food production have established the feasibility of artificial culture of commercially valuable or scientifically useful species of shellfish. However, commercial and experimental shellfish hatcheries frequently experience epizootics which cause high mortalities in larval and postlarval stocks of bivalve mollusks.

A group of gram-negative bacilli, isolated from dead and moribund larvae and juvenile *Mercenaria mercenaria* and *Crassostrea virginica*, were shown by *in vivo* challenge to duplicate spontaneously occurring infections in larvae of homologous and heterologous species, including *Aequipecten irradians*, *Ostrea edulis*, and *Teredo navalis*. Infection and death, with necrosis, proceeded rapidly, spreading from foci of swarming bacteria. "Swarming" was a pathognomonic sign of the disease. Histological examination confirmed the existence of a rapidly developing necrotic bacteremia, and the disease has been designated bacillary necrosis.

The pathogens are members of the order Pseudomonadales, probably of the genus *Aeromonas*. They have been grouped serologically into five antigenic types, and biochemically into four biotypes. They exhibited several unique characteristics when compared with established species and with similar-appearing marine bacteria isolated from normal fauna of Long Island Sound. *In vitro* tests demonstrated a characteristic antibiotic sensitivity pattern for each serotype. *In vivo* studies showed that chloramphenicol and streptomycin could be used for control of the infections.

JOURNAL OF BACTERIOLOGY, Oct., 1965
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Vol. 90, No. 4
Printed in U.S.A.

Bacillary Necrosis, a Disease of Larval and Juvenile Bivalve Mollusks

I. Etiology and Epizootiology

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I. Etiology and Epizootiology

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Received for publication 26 April 1965

ABSTRACT

TUBIASH, HASKELL S. (U.S. Bureau of Commercial Fisheries, Milford, Conn.), PAUL E. CHANLEY, AND EINAR LEIFSON. Bacillary necrosis, a disease of larval and juvenile bivalve mollusks. I. Etiology and epizootiology. J. Bacteriol. 90:1036–1044. 1965.—Lethal bacterial infections of a variety of hatchery-spawned bivalve mollusk larvae and juveniles have been studied. The symptoms of the disease and the course of the infection are described. Four biotypes and five antigenic types of bacteria, pathogenic for the larvae of five species of bivalve mollusks, were isolated and described in some detail. All are gram-negative motile rods. Comparative studies were made of a fairly large number of similar bacteria isolated from presumably normal marine fauna. None of these was pathogenic for the bivalve larvae nor did they have antigens in common with the pathogenic group. The four biotypes had a number of characteristics in common that rarely were present in other cultures from marine fauna. Several antibiotic preparations proved to be of value in the treatment and control of the infection.

Marine pelecypods commonly reproduce by releasing gametes into the water, where external fertilization occurs. Usually, shelled larvae develop within 24 hr (Fig. 1). The larvae are planktonic and swim by the ciliary action of the extended velum. The larvae of the hard clam, *Mercenaria* (*Venus*) *mercenaria*, remain in the free-swimming form for approximately 20 days. After their planktonic existence, they metamorphose into relatively sedentary juvenile forms more closely resembling adults. At metamorphosis, most of the more common marine bivalves average 200 to 400 μ in length (Jørgensen, 1946).

Advances in culture techniques have established the feasibility of culturing desirable species of bivalves commercially (Loosanoff and Davis, 1963; Davis and Ukeles, 1961). However, research groups and pilot-plant shellfish hatcheries are hindered by a disturbingly high incidence of fatal epizootics among larval and juvenile stocks. Sporadic fungal infections believed to be caused by members of the genus *Sirolpidium* were reported in early work on methodology of larval culture of Lamellibranchia (Davis et al., 1954). Guillard (1959) isolated a number of bacterial strains from a single moribund hard clam larva. Broth cultures of two of these strains, identified as *Pseudomonas* sp. and *Vibrio* sp., proved pathogenic to *M. mercenaria* larvae in small axenic test-tube cultures. Recurring losses of larval and juvenile bivalve mollusks in the Milford Laboratory prompted a search for causal microbial agents. The outbreaks were characterized by sudden onset and heavy mortality with characteristic "swarming" of bacteria around the dead and moribund larvae. Many ciliated protozoa were also present.

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MATERIALS AND METHODS

Isolation of pathogens. Moribund larvae of the hard clam, *M. mercenaria*, surrounded by swarming bacteria were collected individually by capillary pipette and washed by threefold centrifugation in sterile seawater. The final washing was decanted, and 1 ml of seawater-Trypticase-glucose-yeast (TGY) broth was added. (TGY broth was composed of 0.4% Trypticase, 0.1% glucose, and 0.1% yeast extract. The medium was adjusted to a final *p*H of 7.4 and autoclaved at 15 psi for 10 min. For solid medium, 1.25% agar was added.) After incubation at 28 C for 4

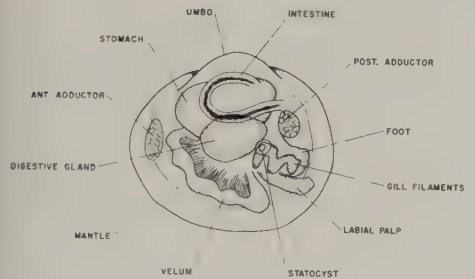

FIG. 1. *Anatomy of a typical bivalve mollusk larva. The velum extends beyond the shell when the animal is swimming. After Jørgensen (1946).*

hr, streak and pour plates were made with TGY agar. The plates were incubated at 28 C for 48 to 72 hr, and colonies were subcultured to agar slants for pathogenicity screening. Tissue was also teased from the gaping shells of moribund juvenile oysters, *Crassostrea virginica*, and juvenile hard clams, *M. mercenaria*, and was cultured in TGY broth as with the larvae. A less tedious technique, adopted subsequently, called for washing dozens to hundreds of affected juveniles or larvae in sterile, round-bottomed, screw-capped centrifuge tubes by fivefold suspension and decantation in sterile seawater. The specimens were ground to a slurry by shaking with sterile glass beads. This homogenate was then plated out in serial dilutions for isolation of predominant bacteria. On occasion, portions of the homogenate were also seeded into healthy larval cultures for rapid determinations of pathogenicity. Isolates which proved pathogenic were preserved by lyophilization in equal volumes of sterile skim milk and seawater.

Pathogenicity screening and range of host susceptibility. A standard test for pathogenicity was performed by inoculating 24-hr suspensions of the test organism into 400-ml cultures of 2- to 7-day-old larvae. Clean, but not sterile, 1-pint (0.47-liter) polyethylene frozen-food containers were employed as convenient culture vessels. Each contained approximately 10,000 larvae in seawater, which had been filtered to remove silt and detritus and ultraviolet-treated to kill protozoa and other plankton. Candidate pathogens were spread on TGY agar slants, incubated for 24 hr at 28 C, washed off with 10 ml of sterile seawater, washed by centrifugation to remove traces of TGY and bacterial metabolites, and diluted to approximately 5×10^8 organisms per milliliter. Larval cultures were seeded with 1- and 2-ml inocula of these bacterial suspensions, incubated at 28 C, and examined for mortality of the larvae after 24 and 28 hr. Suitable pathogenic and saprophytic controls were included, as well as 2-ml seedings of identical bacterial suspensions which had been heated for 30 min at 65 C.

Host susceptibility ranges were determined in a similar manner, except that in addition to *M. mercenaria* and *C. virginica*, larvae of the European oyster (*Ostrea edulis*), bay scallop (*Aequipecten irradians*), and shipworm (*Teredo navalis*) served as hosts for challenge by strain M 17, a pathogen of high virulence. Larvae of *T. navalis* were obtained as the result of a fortuitous single spawning, and incubation was at room temperature (about 20 C) rather than 28 C. Mortality curves were constructed by setting up multiple larval cultures, seeding all simultaneously, and counting viable larvae hourly, one culture per hour, for up to 24 hr. In this manner, an entire larval culture could be sampled and discarded without disturbing the remaining cultures. Differential counts of morbidity and mortality were made by filtering the test larval cultures through a small-mesh (60-μ) stainless-steel wire screen and distributing a representative portion of the larvae thus removed on a Sedgewick-Rafter counting cell. With practice, the dead and moribund larvae, as well as those showing early signs of infection, could be readily differentiated from the normal animals under 100 times magnification. Differential counts were made on 100 evenly distributed larvae. Moribund and dead larvae were counted as "dead"; the rest of the survivors were counted as "alive." Moribund larvae always died within a few hours.

Twenty-seven marine bacterial cultures with morphological and biochemical properties similar to those of the Milford pathogens were screened for pathogenicity and antigenicity. These organisms had been isolated from a variety of normal marine fauna in Long Island Sound and had been studied at Loyola University, Chicago, Ill.

Serological typing. Antigens consisted of live organisms grown for 24 hr on TGY slants, washed, suspended in seawater, and adjusted to a density of approximately 1.5×10^9 organisms per milliliter. Rabbits were immunized by four subcutaneous doses, varying from 0.5 to 2 ml, administered weekly. At 1 week after the final injection, they were bled by cardiac puncture. The sera were separated, inactivated, and tube-tested for agglutinating titer against homologous and heterologous strains of the pathogens. A 0.2-ml volume of the serially diluted serum was mixed with a 0.1-ml suspension of a 24-hr culture of the bacteria, incubated for 4 hr at 15 C, and examined for agglutination. All strains exhibiting pathogenicity for larval bivalves, and the 27 Loyola strains, were tested in this manner.

Identification of pathogens. A typical strain of each of the five antigenic types of the larval pathogens was studied in some detail. Tests for gelatin liquefaction, nitrate reduction, catalase determination, carbohydrate metabolism, and indole formation were performed as described by Leifson et al. (1964). Artificial seawater (one-half strength, pH 7.5 to 8.0) was used for preparing the liquid base medium. Starch-agar was prepared by adding 0.2% soluble starch and 1.5% agar to the base medium. About 1 ml of a 1:10

dilution of Gram's iodine was added to a 2- to 3-day-old slant culture to test for starch utilization. Flagella stains were made according to the method of Leifson (1960), from both agar and slant cultures.

Application and screening of antibacterials. Three proprietary antibacterial formulations were tested, along with chloramphenicol, for therapeutic use against experimental infection with strain M 17: an aqueous preparation containing 250 mg of streptomycin and streptomycin sulfate per ml (Combistrep; Chas. Pfizer & Co., Inc., Brooklyn, N.Y.), sodium sulfamethazine soluble powder (Sulmet; American Cyanamid Co., Wayne, N.J.), and a complex of polyvinylpyrrolidone with 10% free iodine (PVP-iodine).

These formulations had previously been employed empirically to abate shellfish hatchery epizootics. They were evaluated by adding graded levels of the drug, usually 5 to 200 ppm, to 400-ml cultures of clam larvae which had been seeded 4 hr previously with the virulent pathogen. Larval cultures were incubated with the drug for 48 hr at 28 C, and then for 24 hr in new, drug-free water. After the total 72-hr incubation period, counts were made to determine percentage mortality. Controls for drug toxicity were included in all cases.

As the number of pathogenic isolates increased, they were screened for sensitivity to antibiotics by the use of sensitivity discs (Colab Laboratories, Inc., Chicago Heights, Ill.) on TGY agar plates spread with 0.2 ml of 24-hr broth cultures of the test organisms. Antibiotics tested in this manner included: chloramphenicol, kanamycin, neomycin, penicillin, polymyxin B, dihydrostreptomycin, and tetracycline.

RESULTS

Pathology and epizootiology. Two strains of gram-negative bacilli from the isolated moribund clam larvae and three obtained by centrifugation of a group of dead and moribund larvae proved to be highly virulent for larval bivalves. These initial bacterial strains proved to be the etiological agents of a disease we have termed bacillary necrosis. They were typical of many subsequent pathogenic isolates.

The course of this disease in experimentally exposed larvae is swift and dramatic (Fig. 2a). Within 4 to 5 hr after seeding with a virulent pathogen, prodromal signs are a reduction of motility and a tendency for many larvae to lie quiescent with either rudimentary foot or velum extended (Fig. 4b). "Swarms" of bacteria originating from discrete foci on the margins of scattered larvae appear simultaneously. These swarms are a pathognomonic sign of bacillary necrosis, although at this point larvae may seem otherwise normal. The swarms become progressively more dense and ubiquitous, in a manner

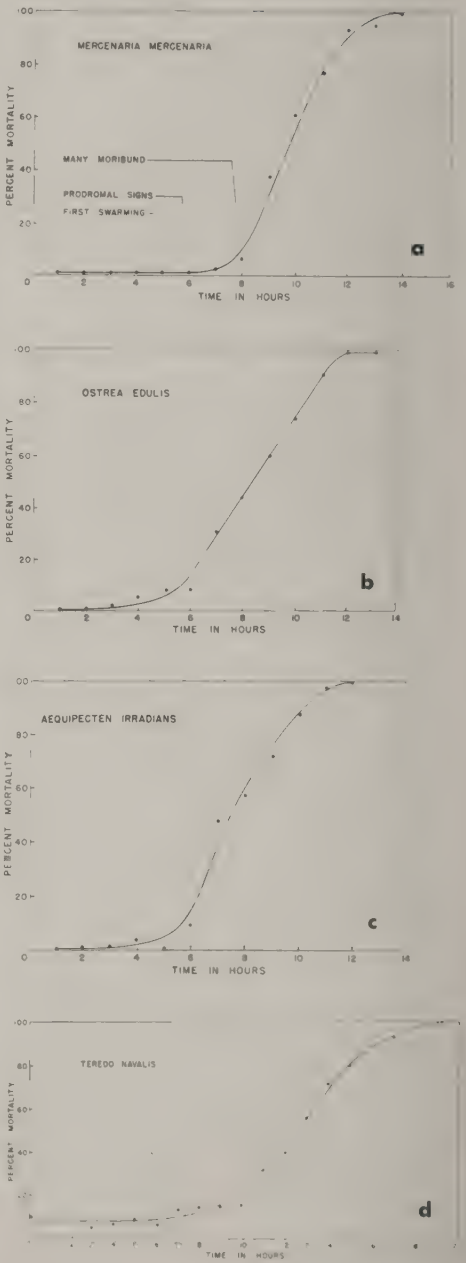

FIG. 2. *Mortality of larvae after challenge with pathogen M 17. (a) Mercenaria mercenaria. (b) Ostrea edulis. (c) Aequipecten irradians. (d) Teredo navalis.*

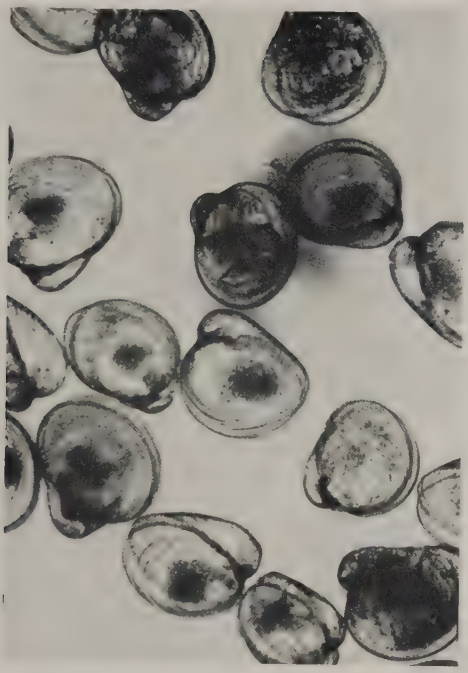

FIG. 3. *Swarms of motile bacteria emanating from heavily parasitized presetting larvae of Crassostrea virginica challenged with pathogen M 17. Swarming proceeds from discrete foci. Soft tissues of most larvae have been or are being necrotized. Viable larvae at top and right corner.* × *140.*

resembling the swarming of bees (Fig. 3). By 8 hr after challenge, death with granular necrosis is widespread. Under low power (100 times), the larval tissues often appear to scintillate from the activity of invading bacteria. In a heavily infected culture, mortality is often complete within 18 hr. Loosely attached or detached portions of the velum frequently continue their ciliary action after all other soft tissues have been destroyed.

The course of an infection induced in straight-hinge larvae of the European oyster, *O. edulis*, by exposure to pathogen M 17 is illustrated in Fig. 4. European oysters are larviparous; fertile ova develop in a brood chamber of the adult for 1 week to 10 days before their release as pelagic larvae. The larvae illustrated were challenged 24 hr after release and experienced an overwhelming, fulminating infection. Ciliated protozoa appeared as scavengers after the height of the bacteria-induced epizootic, and apparently played no part in the primary infection (Fig. 4c). Larvae challenged by pathogenic bacteria that had previously been heated to 65 C for 30 min suffered no mortality and appeared normal in every respect (Fig. 4d).

Histological sections of the larvae, sampled hourly for 24 hr after challenge with pathogen M 17, confirmed a massive bacterial invasion and proliferation, with extensive cellular destruction. These findings support the designation of this disease as bacillary necrosis. A detailed study of the histopathology is in preparation.

Host range. Strain M 17, an early virulent isolate from Milford clam larvae, was pathogenic for all of the lamellibranch larvae challenged (Fig. 2). Subsequently, groups of pathogenic isolates were recovered from moribund juvenile oysters and clams at Milford, as well as from samples of affected juvenile clams from Virginia. The pathogenic strains obtained from oysters were neither as virulent nor as active as those from clams, but each was interchangeably pathogenic for larvae of homologous or heterologous species of all of the lamellibranchs challenged. None of the 27 morphologically and biochemically similar isolates from fauna of Long Island Sound caused appreciable mortality in challenge against larvae of *M. mercenaria*.

Serology. All rabbit antisera agglutinated homologous antigens in dilutions from 1:128 to 1:512 and were tested for cross-agglutination against heterologous antigens. In this manner, five serological strains of pathogens were typed and labeled after their geographical origins: Milford A, J, and O, and Virginia C and D (Table 1). Type A includes four Milford and two Virginia isolates and types C and D each include two Virginia isolates. The three strains comprising type O originated from outbreaks in *C. virginica* larvae. Type J is the latest established, and consists entirely of pathogens isolated from diseased juvenile clams, *M. mercenaria*, at the Milford Laboratory hatchery.

None of the 27 Loyola strains, originating from normal fauna of Long Island Sound, was agglutinated to a significant titer by the antisera for the Milford and Virginia strains (Table 2), nor were they pathogenic for any of the bivalve larvae tested.

Characteristics. The characteristics of the larval pathogens are listed in Table 3.

Morphology. All five antigenic types of larval pathogens, Milford 17 (type A), Milford 27 (type O), Milford 74 (type J), Virginia 65 (type D), and Virginia 67 (type C), were composed of gram-negative small rods, measuring about 0.5 by 1.5 μ. Some individuals of strains M 17 and V 65 showed slight somatic curvature. Members of the other strains were quite straight. All strains

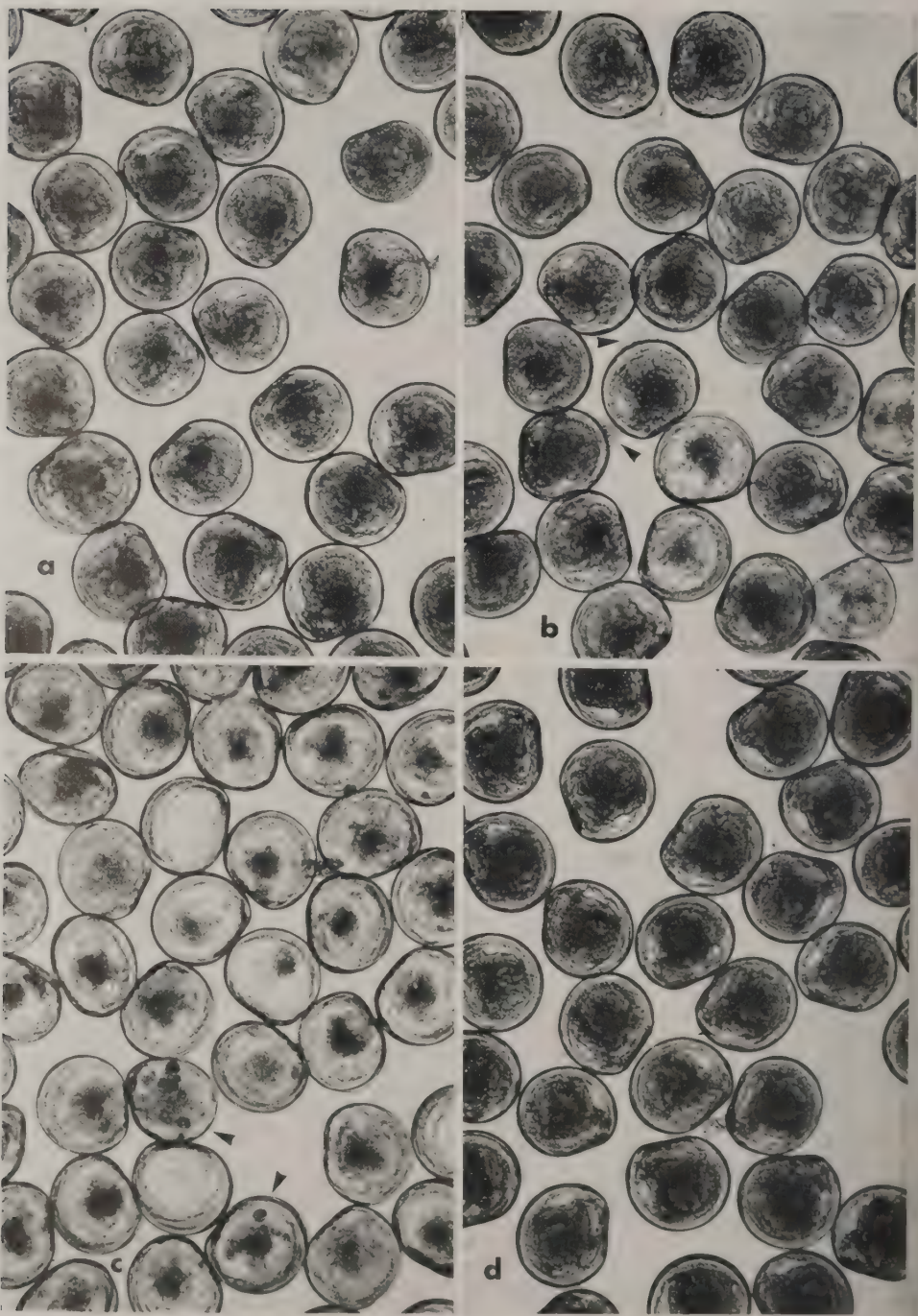

FIG. 4

TABLE 1. *Serological typing of bivalve pathogens*

Type	Strain	Isolate
Milford	A	17
		20A
		20C
		63VA
		64VA
		70
	J	71
		72
		73
		74
		76
	O	27
		30
		32
Virginia	C	61VA
		67VA
	D	65VA
		66VA

TABLE 2. *Agglutination titers of Loyola strains of marine bacteria*

Antigen	Antiserum A	J	O	C	D
Loyola strains					
23 strains	—	—	—	—	—
LA 7	8*	—	4	—	—
LO 20	4	—	—	—	—
LO 23	—	8	—	—	—
LC 26	—	—	8	—	—
Controls					
A 17	128	—	—	—	
J 71		128	—	—	
O 27	—	—	256	—	—
C 61	—	—	—	256	—
D 65	—	—	—	—	128

* Agglutination titer equals reciprocal of serum dilution causing agglutination. Loyola series showed no significant agglutination with Milford antisera.

showed polar monotrichous flagellation when stained from liquid cultures (Fig. 5a and b).

The average wavelength of the polar flagella was 1.8 to 2.0 μ for all five cultures. When stained from either broth or agar slant cultures, strains M 27 and M 74 were polar monotrichous flagellate. Strain M 17 showed a few individuals with one or more lateral flagella of relatively short wavelength (about 1.2 μ). In addition to the polar flagellum of normal wavelength, strains V 65 and V 67 showed numerous loose, flagella of short wavelength. This phenomenon was described by Leifson (1964) and is characteristic of polar flagellate marine bacteria which "swarm" on agar media.

Cultural characteristics. Growth was uniformly turbid, colorless, and dense in the liquid base medium. On agar, growth was smooth and colorless; strains M 17 and V 65 were very mucoid, and V 67 swarmed on solid media. All strains were halophilic and grew luxuriantly in simple peptone-yeast extract medium with the addition of 3% sodium chloride. All strains were more or less psychrophilic, and at 37 C either failed to grow or grew very slowly as compared with growth at 20 and 30 C. All grew well in media of *p*H 7 to 9. A characteristic of all five strains was their brief longevity when cultures were stored at 4 C. Most strains of fermentative marine bacteria in the Leifson collection could be maintained in a refrigerator by transfer every 2 months, whereas the larval pathogens invariably were dead after this period of storage. The same situation was found with cultures of *Pseudomonas piscicida*, a fish pathogen, which also died after a few weeks of storage. However, larval pathogens proved to be viable after more than 2 years of lyophilized storage.

Physiological characteristics. Strains M 27 and M 74 were morphologically and physiologically indistinguishable. The remaining strains had many characteristics in common but also exhibited differences (Table 3).

Perhaps the most definitive characteristics of the pathogenic group are: polar monotrichous flagellation in liquid media, fermentative anaerogenic metabolism of carbohydrates, gelatin liquefaction, starch hydrolysis, and a negative or weak catalase reaction. Few cultures of bacteria isolated from presumably normal Long Island Sound animals had all of the characteristics common to the larval pathogens.

FIG. 4. *Larvae of European oyster challenged with M 17. × 140. (a) At 1 hr after infection. Larvae appear normal. (b) At 7 hr after infection. Several heavily infected larvae show necrosis of internal tissues; arrows indicate two exhibiting characteristic extension of the velum after infection. Larvae have been fixed in formalin and do not show swarming bacteria which were seen in the living preparation. (c) At 13 hr after infection. Almost all have been infected and necrotized by the pathogen. Arrows indicate secondary invasion by ciliated protozoa. (d) At 24 hr after seeding with a suspension of pathogen which had been heated at 65 C for 30 min. Larvae appear healthy and identical to normal controls.*

TABLE 3. *Characteristics of larval bivalve pathogens**

Characteristic	M27	M74	M17	V65	V67
NaCl-free base broth	−	−	−	−	−
Base broth plus 3% NaCl	+++	+++	+++	+++	+++
Growth at 37 C	−	$+_w$	$+_w$	+	−
Gelatin liquefaction	++	++	++	++	++
Dextrose fermentation	+++	+++	+++	+++	+++
Sucrose fermentation	+++	+++	+++	+++	+++
Maltose fermentation	+++	+++	+++	+++	+++
Starch hydrolysis	+++	+++	+++	+++	+++
Lactose fermentation	−	−	−	−	−
Xylose fermentation	−	−	−	−	−
Catalase reaction	+/−	+/−	+/−	+/−	+/−
Nitrate to nitrite	+++	+++	+++	+++	−
Indole formation	+++	+++	−	+++	−
Mannitol fermentation	+++	+++	+++	−	−
Phenylalanine deaminase	+++	+++	−	+++	−
Swarming on agar	−	−	−	+	+++
Lateral flagella on agar	−	−	+	+++	+++
Wavelength of polar flagella	1.9	1.9	2.0	1.7	1.9
Somatic curvature	−	−	+	+	−

* Symbols: − = lack of growth, acid production, or any negative reaction; + = degree of growth, acid production, or any positive reaction; $+_w$ = slight or weak growth.

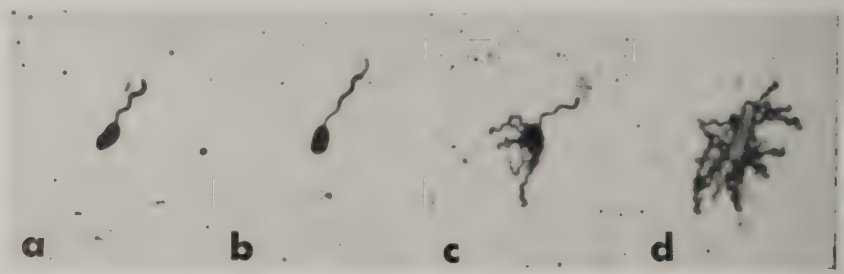

FIG. 5. *Flagellation of pathogenic strains. Leifson stain. (a) Strain V 65 showing polar monotrichous flagellation and slight somatic curvature. Stained from liquid culture. Strain M 17 had the same morphology. (b) Strain V 67 stained from liquid medium, showing polar monotrichous flagellation and straight soma. Strains M 27, M 74, and V 67 showed the same morphology when stained from liquid media. (c) Strain V 67 stained from agar slant culture. The polar flagellum is present along with the lateral flagella of shorter wavelength. (d) Strain V 67 stained from agar slant culture. Only lateral flagella are seen. Strain V 65 showed this same morphology when stained from slant culture. Strain M 17 also showed an occasional lateral flagellum.*

Control of infection with antibacterials. In vitro assays with antibiotic sensitivity discs against type cultures of the pathogenic serotypes revealed that all were in some degree sensitive to four antibiotics: chloramphenicol, polymyxin B, erythromycin, and neomycin (Table 4).

Combistrep added to the seawater in larval cultures proved very effective as a therapeutic agent against challenge with organism M 17 (Table 5). We found that 50 to 100 ppm of the antibiotic (200 to 400 ppm of Combistrep) were useful, experimentally, for therapeutic application. This veterinary preparation, developed for treatment of poultry, also enhanced larval growth in concentrations up to 2,000 ppm (Hidu and Tubiash, Proc. Natl. Shellfisheries Assoc., *in press*). Chloramphenicol was equally effective against pathogen M 17. Although Sulmet was well tolerated by larvae at very high levels, it demonstrated no protective properties. PVP

TABLE 4. *Antibiotic sensitivity of bivalve pathogens*

Antibiotic	Serotype cultures				
	M17 (A)	M27 (O)	V67 (C)	V65 (D)	M74 (J)
Chloramphenicol	+*	+	+	+	+
Erythromycin	+	+	+	+	+
Kanamycin	+	0	0	+	0
Neomycin	+	+	+	+	+
Penicillin	0	+	0	0	+
Polymyxin B	+	+	+	+	+
Streptomycin	+	0	0	+	0
Tetracycline	0	0	+	+	+

* Plus indicates zone of inhibition with high-concentration Colab Multidisks.

TABLE 5. *Therapeutic effect of antibacterials challenged with pathogen M17*

Drug level in water of larval culture	Drug	Per cent larval survival* (72 hr)
ppm		
0	Unprotected (positive) control	0
5	Chloramphenicol	78
10	Chloramphenicol	91
20	Chloramphenicol	91
50	Chloramphenicol	98
	Combistrep	99
	PVP-iodine	0
100	Chloramphenicol	100
	Combistrep	99
	PVP-iodine	0
	Sulmet	0
200	Combistrep	100
	Sulmet	0
300	Sulmet	0

* All uninoculated drug controls were satisfactory except PVP-iodine, which was toxic to larvae at 100 ppm.

iodine proved toxic to larvae at potentially useful concentrations. Preliminary tests with polymyxin B sulfate, erythromycin, and neomycin sulfate indicate that these drugs are tolerated by larvae at concentrations which may be therapeutically useful.

DISCUSSION

The bacilli found to be pathogenic for the various bivalve larvae were of the type commonly classified as either *Aeromonas* sp. or *Vibrio* sp. The slight somatic curvature of some individuals of strains M 17 and V 65 probably has little taxonomic significance. The five larval pathogens had many characteristics in common (Table 3), but could be classified into four biotypes, as well as into the five antigenic types. A multiplicity of serological types is no surprise in view of similar situations among bacterial and viral disease agents of higher animals.

None of the cultures isolated from presumably normal marine fauna, and with generally similar morphological and physiological characteristics, had antigens in common with the larval pathogens, and none was pathogenic for bivalve larvae. Despite these results, it is felt that, in all probability, the etiological agents of bacillary necrosis normally exist as widely distributed saprophytes or commensals of marine forms, since typable pathogens were frequently isolated from cultures maintained in unsanitary or otherwise unfavorable physical environment.

The route of infection has not yet been defined but, as a rule, the few malformed larvae found in both experimentally and spontaneously infected cultures were the last to show signs of infection and survived the longest. Since, unlike healthy larvae, these abnormal forms seldom feed, it is probable that the initial invasion of the pathogen is through the larval alimentary tract. The question of the route of entry should be resolved by current histopathological studies. On the other hand, adult hard clams, American oysters, blue mussels (*Mytilus edulis*), and soft clams (*Mya arenaria*), exposed to massive concentrations of all pathogenic serotypes for 24 hr in standing seawater cultures, showed no ill effects, although these filter-feeders ingested vast numbers of the test bacteria.

Antibiotic preparations apparently can be used effectively in the prevention and treatment of larval hatchery infections and may offer a practical short-term means of control. Discovery of the sources of the infectious agents, of conditions that encourage their proliferation, and of environmental factors which predispose bivalve larvae to invasion by these bacteria might serve to clarify the epizootiology of bacillary necrosis and establish a rational basis for hatchery sanitation procedures.

ACKNOWLEDGMENTS

We thank Manton Botsford for preparing the figures and photomicrographs, and Rudolph Hugh and Graham L. Bullock for examining the pathogens. Chloramphenicol was supplied through the courtesy of Parke, Davis & Co., Detroit, Mich.

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Vol. 10, No. 3, July 1965
pp. 492–495

A SIMPLE METHOD FOR THE MASS CULTURE OF MARINE ALGAE

BY RAVENNA UKELES

A Simple Method for the Mass Culture of Marine Algae

Interest in the mass culture of unicellular algae stems from several sources. Algal culture is being investigated for use in space vehicles as a means of air revitalization, food production, and waste treatment (Benoit 1964). In many overpopulated areas of the world, unicellular algae are considered a potential food supplement for direct human consumption or as food for other animals (Witsch 1960; Spoehr 1953).

Dried algae are now used to supplement livestock feed in China (Choi[1], personal communication; Nakamura 1964). In this laboratory, marine species of unicellular algae are used as foods for oyster and clam larvae in pilot-plant hatchery operations (Loosanoff and Davis 1963). The adoption of hatchery culture of bivalves by industry will bring about an additional demand for a simple inexpensive method of culturing large amounts of algae.

Studies on the mass culture of algae have been largely confined to freshwater species of *Chlorella* and *Scenedesmus* (Burlew 1953; Mayer 1960), probably because of their survival in a variety of environmental conditions and widespread availability. However, these may not necessarily be the most suitable species for some purposes. As was suggested by Mayer (1960), it would be desirable to screen a large number of unicellular algae from the point of view of nutritional composition, toxicity, resistance to contaminants, growth rates in mass culture, and suitability for the particular use intended. The significance of the latter point was demonstrated by observations that larval and juvenile stages of *Crassostrea virginica* and *Mercenaria mercenaria* and larvae of *Ostrea edulis* used certain species of algae as a food source better than others (Davis and Guillard 1958; Walne 1963). This work represents an attempt to determine the feasibility of culturing *Chlorella* and other unicellular marine algae, using a simple method that could be employed in many parts of the world under a variety of conditions. Mass culture can be carried out in the laboratory with good results, but the conditions in some areas are so primitive that glass jars or tubes, artificial illumination, and equipment for sterilizing large volumes of seawater may not be available, and some locations make the large scale culture of marine species impossible. It is important therefore to find unsophisticated methods for the production of large quantities of marine species.

Other investigations into the mass culture of marine algae have depended on natural seawater, both in open tanks and in closed controlled systems (Loosanoff 1951; Raymont and Adams 1958; Wisely and Purday 1961; Davis and Ukeles 1961; Ansell et al. 1963). Although fertilized natural seawater produced a good crop of phytoplankton, the inoculated culture was sometimes replaced rapidly by other organisms introduced with the seawater, such as motile and nonmotile chlorophytes, colorless flagellates, ciliates or other zooplankters (Loosanoff, Hanks, and Ganaros 1957; Ansell et al. 1963). Even under controlled laboratory conditions (Davis and Ukeles 1961), small algal species in seawater occasionally pass through filters and become established in culture carboys. It would be advantageous to use an artificial salt water medium which would

[1] Prof. Ki Chul Choi, Dept. of Biology, Seoul National University, Seoul, Korea.

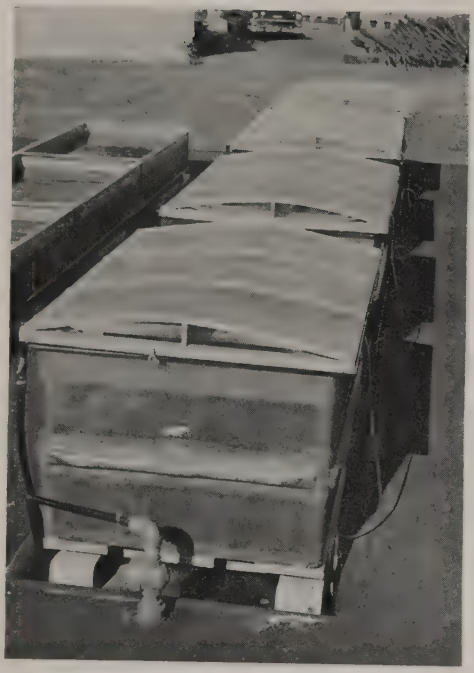

FIG. 1. Outdoor culture tanks, with covers in place, showing valve that regulates the supply of cooling seawater.

FIG. 2. Culture tanks, with covers removed to show culture vessel inside cooling bath and the aerating and siphoning systems.

eliminate the immediate introduction of undesirable organisms. Preliminary laboratory experiments in which growth of axenic cultures was measured under controlled conditions indicated that the commercially prepared salt mixture, Rila Marine Mix[2], might be used. The salt was dissolved in distilled, demineralized, or tap water, and supplemented with a nitrogen source and a vitamin mix of thiamine and B_{12}. This type of culture medium was used in laboratory mass cultures in place of the natural seawater previously employed (Davis and Ukeles 1961). Excellent growth of *Monochrysis lutheri, Isochrysis galbana, Phaeodactylum tricornutum*, and *Dicrateria* sp. was obtained during a period of 6 months in continuous culture.

A similar basal medium made up with Rila salts was used in cultures maintained outdoors in 280-liter fiber glass tanks. Each culture tank was placed inside a larger fiber glass tank and secured on a frame so that the water level in the inner tank was slightly higher than that in the outer tank. Seawater pumped from the nearby harbor was continuously circulated in the outer tank which thereby served as a cooling bath for the culture. Several aquarium-type stone aerators were placed in each culture tank and connected to a Marco®[3] air pump to provide aeration and stirring in the bottom of the culture. Each pair of nested tanks was covered with heavy-duty polyoxyethylene sheeting stretched over a wooden frame (Figs. 1 and 2).

The tanks were filled with tap water and Rila Marine Mix (2.0%w/v) was added, supplemented with urea (0.02%w/

[2] Rila Products, Teaneck, New Jersey.

[3] Registered trademark, J. B. Maris Co., Bloomfield, New Jersey.

v), tris (hydroxymethyl) aminomethane (0.2%w/v) and the vitamin mixture (thiamine 0.02 mg and vitamin B_{12} 0.2 μg/100 ml). Each tank was inoculated with 10 liters of a culture taken from the unialgal mass culture apparatus maintained in the laboratory. The growth response of the following four species was followed during the summer: *Dunaliella euchlora*[4], *Chlorella* sp. (580), *Dicrateria* sp., and *Monochrysis lutheri.*

The temperature of the cultures ranged from 19.5 to 23.0C, even during an extremely warm period when air temperatures were as high as 38.0C. The *p*H of the cultures varied from 7.9 to 9.1 and was relatively high in the afternoon and low in the early morning. During the first month of growth, only an occasional ciliate and a few diatoms were observed as gross contaminants. Cell counts revealed an initial increase in cell populations. The population in each tank was 0.3×10^6 cells/ml with the exception of *Chlorella* sp., where the initial population was about 10 times as high. Within 10 days there was an increase to 1.9×10^6 cells/ml for *M. lutheri*, 1.4×10^6 cells/ml for *Dicrateria* sp., 0.7×10^6 cells/ml for *D. euchlora*, and 8.7×10^6 cells/ml for *Chlorella* sp. (580). The initial increase was followed by a period of decline when cultures were being harvested (for use as foods in pilot-plant hatchery studies) at a rate of 60–100 liters a day from each tank. All cultures were used as foods by juvenile stages of oysters and clams with good results.

The most consistent maintenance of population levels and the least amount of invasion by other species occurred in the *Chlorella* culture. In contrast, there was little growth of *D. euchlora*, and the culture was eventually overgrown with diatoms. The observation that growth of *D. euchlora* was poor in this medium was confirmed in laboratory mass cultures. The addition of phosphate increased the populations of *D. euchlora* to levels equivalent to those obtained when enriched natural seawater was used as the basal medium. Obvious benefit to other species in culture was also observed. All species that were maintained in natural seawater in the mass culture apparatus previously described (Davis and Ukeles 1961) are now being cultured in this enriched artificial seawater medium. The chemical composition of Rila salts is given by the manufacturer so that appropriate modifications can be made for particular species as nutritional information becomes available. An increased yield in outdoor tanks can be anticipated in future work.

While investigating the mass culture of *Phaeodactylum tricornutum* in 1,000-liter outdoor concrete tanks, Ansell et al. (1963) encountered difficulty in controlling environmental conditions, as well as in maintaining such large cultures. In subsequent work, it was found more convenient to use 15-liter carboys (Ansell, Raymont, and Lander 1963). Tanks of an intermediate size make it possible to maintain relatively large volumes of a variety of species, and the cultures can be harvested or discarded without great loss. Fiber glass is a satisfactory material for the construction of culture tanks because it can be handled and shaped easily, it is sturdy enough for repeated outdoor use, and it is relatively nontoxic. Although plastics are generally not inhibitory, it is necessary to test each formulation (Dyer and Richardson 1962). It is a good practice to fill each tank with water and treat with successive washes before use. Enrichment conditions and a heavy inoculum of one species should establish conditions that suppress the growth of other organisms in the culture tank. A species can be cultured until undesirable contamination appears, then harvested, and the cells stored under refrigeration, dried or lyophilized.

This work has demonstrated that a variety of unicellular marine algae can be cultured on a large scale in artificial seawater with a minimum expenditure. Improvements will ultimately depend upon data

[4] This strain may be identical with *D. tertiolecta* Butcher (McLachlan 1960).

obtained in the laboratory on optimal conditions for algal growth.

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INHIBITION OF UNICELLULAR ALGAE BY SYNTHETIC SURFACE-ACTIVE AGENTS

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Reprinted from JOURNAL OF PHYCOLOGY
Vol. 1, No. 3, pp. 102–110 (1965)
Made in United States of America

J. Phycol. 1, 102–110 (1965)

INHIBITION OF UNICELLULAR ALGAE BY SYNTHETIC SURFACE-ACTIVE AGENTS

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SUMMARY

The effects of non-ionic, anionic and cationic detergents on 12 species of marine phytoplankton were observed. Although individual species varied widely in response, growth inhibition in non-ionic surfactants became more pronounced as the surface-active properties of the agents tested increased. The tolerances of species belonging to the same family were generally similar, and each family had a specific inhibition pattern. Anionic detergents inhibited growth in concentration ranges that depended on the species and the surfactant. All species were more sensitive to the cationic agent than to anionic or non-ionic agents. The significance of these results was discussed.

Surface-active agents have long interested biologists. Much early work dealt with hemolysis by such natural surface-active agents as saponin and bile salts (*27*). With the advent of synthetic surface-active agents, work consisted largely of evaluating detergents as bactericides (*14*). Other effects were also observed, e.g., production of diffuse homogeneous growth of mycobacteria in submerged culture (*9*). Some surface-active agents stimulate bacterial growth at low concentrations (*22*), and a similar observation was made for the early growth phases of the ciliate, *Tetrahymena pyriformis* (*18*). The effect of 3 detergents on the growth of the green alga, *Ankistrodesmus convolutus*, was reported (*39*) but no systematic study of different types of detergents on a group of related microorganisms has been made. The effects of several synthetic detergents on the growth of 12 species of marine phytoplankton in the Chlorophyceae are described here.

MATERIALS AND METHODS

Representatives of each of the 3 general categories of detergents, i.e., non-ionic, anionic, and cationic, were included in this study (Table 1).

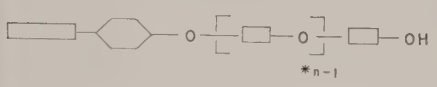
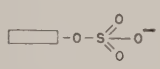
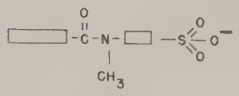
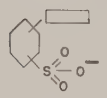
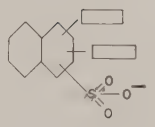
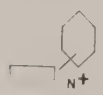
The non-ionic surfactants tested were members of the Igepal[1] series, CO-610, CO-630, CO-710, CO-730, CO-850, CO-880, and Tweens, 20, 40, and 80. Non-ionic surface-active agents balance hydrophobic with non-ionized hydrophilic groups. The Igepals are derived from the same hydrophobic starting material, nonylphenol (a trade designation for a mixture of isomeric monoalkyl phenols), but differ in the amount of the hydrophilic component, ethylene oxide. By increasing the ratio ethylene oxide : nonylphenol, products with different hydrophilic-hydrophobic balances are obtained. There is a versatile balance in Igepal CO-630, but in lower numbers the product is less hydrophilic and more hydrophobic; the numbers above CO-630 indicate that the ratio is reversed. The Tweens derive from condensation of polyoxyethylene with fatty acid esters of hexitol anhydrides. All have high hydrophilic : hydrophobic ratios (*33*) but differ in the fatty acid component: Tween 20 is a monolaurate; Tween 40 a monopalmitate; and Tween 80 a monooleate.

Four anionic surfactants were tested, including two of the alkyl aryl type, alkyl naphthalene sulfonate (Nekal BX-78) and alkyl benzene sulfonate (ABS), as well as two examples of the alkyl type, Mg lauryl sulfate (Conco Sulfate M) and the sulfonated amide of oleoyl methyl taurine (Igepon T-77). Anionic surface-active agents are characterized by hydrophobic residues as paraffinic chains or alkyl-substituted benzene or naphthalene rings. These residues, together with negatively charged hydrophilic groups, such as carboxyl, sulfate, sulfonate or phosphate, form anions of large mass.

Lauryl pyridinium chloride, a nitrogen ring compound, was the only cationic detergent tested. In cationic detergents a fatty acid and a positively charged hydrophilic group, as quarternary ammonium, form a large cation. In addition to the ordinary substituted ammonium compounds, pentavalent nitrogen ring compounds are also considered quarternary ammonium compounds (*30*).

[1] Trade names referred to in this publication do not imply endorsement of commercial products.

TABLE 1. *Classification of detergents*

Classification	Generalized structure[1] (ionic form)	Trade name and source	Chemical description
Non-ionic			
Polyether alcohols		*Igepal*** (General Aniline & Film Corp.) [2]	
		Igepal CO-610	Alkylphenoxypoly(ethyleneoxy)ethanol n* = 9
		" CO-630	" n = 9.5
		" CO-710	" n = 10.5
		" CO-730	" n = 15.0
		" CO-850	" n = 20.0
		" CO-880	" n = 30.0
Derivatives of esters of polyhydric anhydrides and fatty acids		*Tween*** (Nutritional Biochemicals)	
		Tween 20	Polyoxyethylene sorbitan monolaurate
		" 40	" " monopalmitate
		" 80	" " monooleate
Anionic			
Alkyl types		Conco** Sulfate M (Continental Chemical Co.) [2]	Mg lauryl sulphate 26–28%
		Igepon T-77** (General Aniline & Film Corp.) [2]	Na N-methyl-N-oleoyl taurate-67% + Na oleate 8%
Alkyl aryl types		Alkyl benzene sulfonate (Assoc. Am. Soap and Glycerine Mfgs.) [2]	Major component, Na-N-dodecyl benzene sulfonate 54%
		Nekal BX-78** (General Aniline and Film Corp.) [2]	Na dibutyl naphthalene sulfonate and Na diisopropyl naphthalene sulfonate 82% + 18–22% Na oleate
Cationic			
Alkyl derivatives of aromatic amines		L.P.C. (Hooker Chem. Corp.) [2]	Lauryl pyridinium chloride

* n = moles of ethylene oxide per mole of nonylphenol.
** Registered trademark.
[1] Paraffin chain represented by rectangular strips, adapted from Price (*28*).
[2] Agents were generously contributed by manufacturer.

The organisms were cultured in 20 × 150 mm Pyrex screw-cap test tubes containing 10 ml of media. The basal medium (Table 2) was adjusted to pH 8.0 and the media autoclaved at 15 lb. for 20 min. The agents were used as obtained commercially and dissolved in distilled water. Concentrated solutions of detergents were sterilized by Millipore[2] filtration and added aseptically to the autoclaved basal medium to give (w/v) 0.1%, 0.01%, 0.001%, 0.0001%, and in one case 0.00001% of the whole product. After addition of the test agent each tube was inoculated with 0.5 ml of an axenic stock culture at the stationary growth phase. Cultures were incubated in a constant-temperature room at 20.5 ± 1° C with a light intensity of about 500 ft-candles produced by a bank of cool-white fluorescent lights. All the species studied and their sources are listed (Table 3) according to Silva's classification (*32*). Optical density readings of growth were taken in a DU Beckman spectrophotometer at 520 mμ after incubation for 12–14 days, and growth in experimental tubes was expressed as % of growth in control cultures. The optical densities reached by control cultures were between 0.400 and 0.650. Species that demonstrated identical patterns of complete inhibition were grouped together and, where inhibition was partial, densities of these species were averaged and plotted as % control growth.

[2] Registered trademark, Millipore Filter Corporation, Bedford, Massachusetts.

RESULTS

Non-ionics. Growth in non-ionic detergents of the Igepal series was significantly inhibited at concentra-

TABLE 2. *Composition of basal medium*

$NaNO_3$	150.0	mg
KH_2PO_4	20.0	"
NaFe Sequestrene (13% Fe)	10.0	"
$CuSO_4 \cdot 5H_2O$	0.02	"
$ZnSO_4 \cdot 7H_2O$	0.04	"
$CoCl_2 \cdot 6H_2O$	0.02	"
$MnCl_2 \cdot 4H_2O$	0.36	"
$Na_2MoO_4 \cdot 2H_2O$	0.01	"
NH_4Cl	50.0	"
Thiamine·HCl	0.2	"
Vitamin B_{12}	0.002	"
Tris (hydroxymethyl) aminomethane	1	gm
Sea water (salinity 22–27‰) to	1	liter

TABLE 3. *Classification and sources of chlorophytes*

Order Volvocales	
Family Chlamydomonadaceae	
1. *Chlamydomonas* sp.	Pringsheim collection #11/35
2. *Carteria* sp.	Milford isolate
3. *Platymonas* sp.	Milford isolate
Family Polyblepharidaceae	
4. *Dunaliella euchlora**	Ryther isolate
5. *Dunaliella primolecta*	Plymouth collection #81
6. *Pyramimonas grossi*	Plymouth collection#78
Order Chlorococcales	
Family Chlorellaceae	
7. *Chlorella* sp.	Indiana collection #580
8. *Chlorella stigmatophora*	Plymouth collection #85
Family Chlorococcaceae	
9. *Chlorococcum* sp. C	Milford isolate
Order Ulotrichales	
Family Ulotrichaceae	
10. *Stichococcus* sp. GSB	Ryther isolate
Family Protococcaceae (Pleurococcaceae)	
11. *Protococcus* (Pleurococcus) sp.	Milford isolate
Order Chlorosphaerales	
Family Coccomyxaceae	
12. *Nannochloris* sp.	Milford isolate

* This strain may be identical to *D. tertiolecta* Butcher.

tions from 0.001% to 0.1%. Although there was variation in susceptibility between species, each species was relatively less inhibited in the higher Igepal numbers than in the lower ones.

The non-ionics most inhibited *Stichococcus* GSB and *Nannochloris* sp. (Fig. 1). Both organisms showed the same pattern of inhibition in which 0.1% and 0.01% of each of the Igepal detergents completely inhibited growth. Igepal CO-610, CO-630, and CO-710, at 0.001% also completely inhibited growth but in CO-730 there was 40% inhibition (30% for *Stichococcus* and 50% for *Nannochloris*). Inhibition was minimal at this concentration in CO-850 and CO-880. Growth like the controls was found with all Igepals at 0.0001%, but also with a somewhat better response in CO-880 than in CO-610. Similarly, *Chlorella* sp. (#580) and *Chlorella stigmatophora* grew best in 0.0001% CO-610 through CO-880 (Fig. 2). However, unlike the species previously discussed, there was some growth in 0.001% CO-610 with about 50% (43% and 57%) inhibition which decreased as the Igepal number increased. There was complete inhibition of both species of *Chlorella* in 0.01% of CO-610, CO-630, CO-710, CO-730, and CO-850, but only about 24% (30% and 18%) inhibition in CO-880. At 0.1% growth was partly inhibited in CO-880 but completely inhibited in the lower Igepal numbers.

The flagellates, *Carteria* sp., *Platymonas* sp., and *Chlamydomonas* sp. are next in decreasing order of sensitivity (Fig. 3). As with *Chlorella*, growth was comparable to the controls in the lowest concentrations of Igepal CO-610 through CO-880. In the next highest concentration (0.001%) there was partial inhibition of the 3 flagellates in CO-610 (*Carteria* sp. 47%, *Platymonas* sp. 44%, and *Chlamydomonas* sp. 30%) which decreased to density values equal to

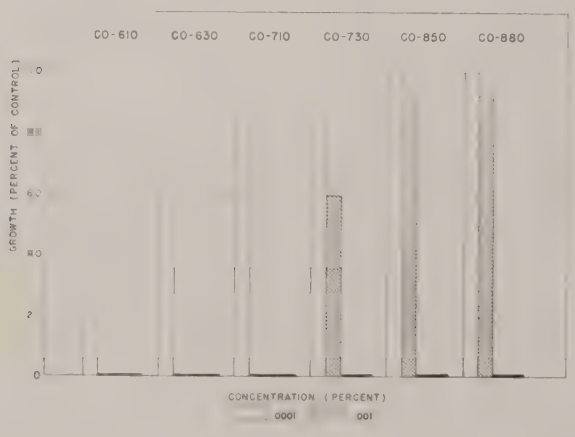


FIG. 1. Effect of Igepals on the growth of *Stichococcus* sp. GSB and *Nannochloris* sp.

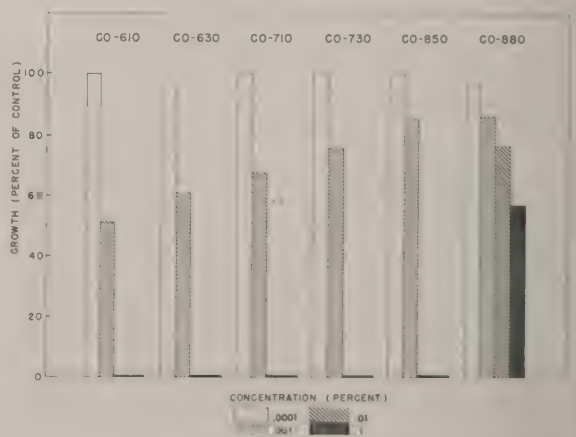


FIG. 2. Effect of Igepals on growth of *Chlorella* #580 and on *C. stigmatophora*.

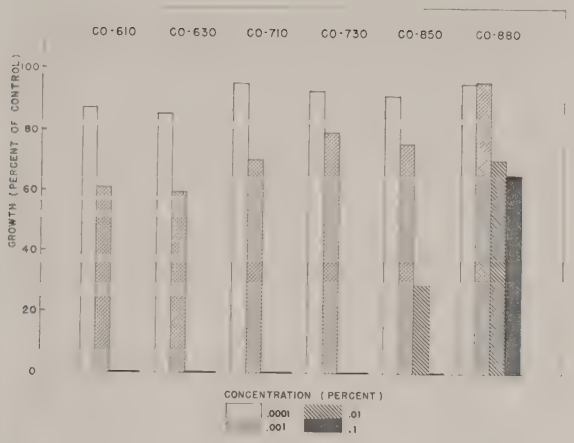


FIG. 3. Effect of Igepals on growth of *Platymonas* sp., *Chlamydomonas* sp., and *Carteria* sp.

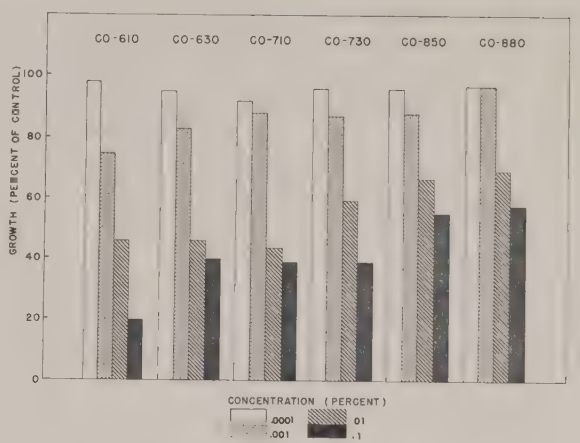


FIG. 5. Effect of Igepals on growth of *D. euchlora*, *D. primolecta*, and *P. grossi*.

the controls in the most hydrophilic member. At 0.01%, Igepal CO-610, CO-630, CO-710, and CO-730 completely inhibited growth, but unlike the other species discussed, these flagellates made some growth in CO-850 although the % inhibition was high (70%). However, in CO-880 there was only about 30% inhibition. The highest concentration (0.1%) inhibited growth in CO-610 through CO-850 but not in CO-880, where growth only partly decreased.

Chlorococcum sp. C had another distinctive inhibition pattern (Fig. 4). The growth response was like that described for *Chlorella* and the flagellates in CO-610 through CO-730 since growth did not occur in 0.1 and 0.01%. However, with *Chlorococcum* sp. C there was growth in all 4 concentrations of CO-850, as well as in all concentrations of CO-880, although growth was generally poor in the highest concentrations.

In contrast to the species already discussed, growth of the motile flagellates, *Dunaliella euchlora*, *Dunaliella primolecta*, and *Pyramimonas grossi*, occurred in all Igepals (Fig. 5) at the test concentrations. Growth in the highest concentration of Igepal CO-610 was decreased by an average of 80%, but there was only about 40% inhibition in CO-880. At 0.01% inhibition decreased from 66% in CO-610 to 30% in CO-880. At 0.001%, there was only 25% inhibition in CO-610 and no inhibition in CO-880, and at 0.0001% growth equalled the controls for CO-610 through CO-880.

The pattern for *Protococcus* sp. was essentially the same as that described for the latter flagellates, since growth occurred in all members of the series. However, the pattern may be considered distinctive because in contrast to the flagellates growth of *Protococcus* sp. was at least equal to the controls in all Igepals with the exception of CO-610 at 0.1% (Fig. 6).

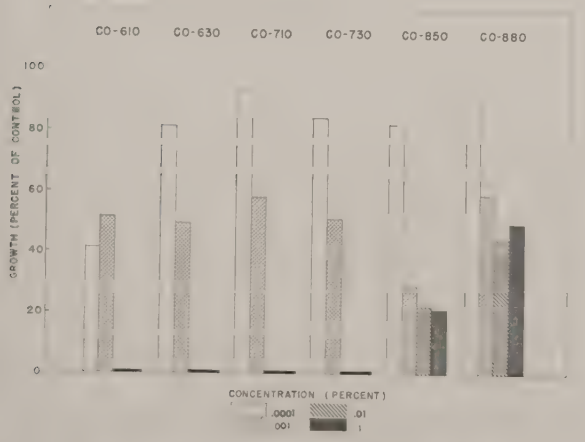


FIG. 4. Effect of Igepals on growth of *Chlorococcum* sp. C.

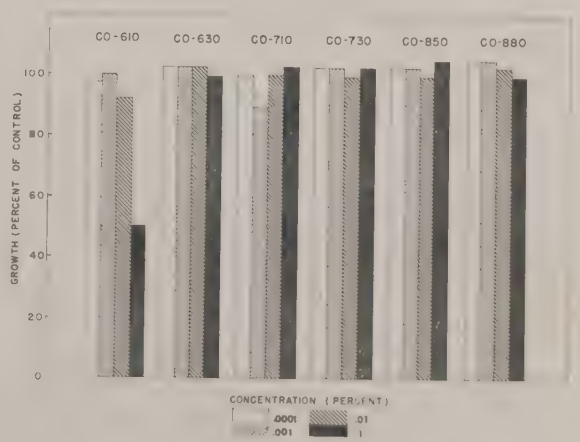


FIG. 6. Effect of Igepals on growth of *Protococcus* sp.

TABLE 4. *Effect of Tweens on growth*

Species	Tween 20			Tween 40			Tween 80		
	0.001 %	0.01 %	0.1 %	0.001 %	0.01 %	0.1 %	0.001 %	0.01 %	0.1 %
Chlamydomonas sp. (#11/35)	+	+	±	+	+	+	+	+	+
Carteria sp.	+	+	+	+	+	+	+	+	+
Platymonas sp.	+	+	+	+	+	+	+	+	+
Dunaliella euchlora	+	+	+	+	+	+	+	+	+
Dunaliella primolecta	++	++	++	+	++	++	+	++	++
Pyramimonas grossi	++	++	++	+	+	++	+	+	++
Chlorella sp. (#580)	+	+	+	+	+	0	+	+	+
Chlorella stigmatophora	+	±	0	+	+	0	+	+	+
Chlorococcum sp.	+	+	+	+	+	+	+	+	+
Protococcus sp.	+	+	+	+	+	+	+	+	+
Stichococcus sp. (GSB)	+	0	0	±	0	0	+	0	0
Nannochloris sp.	+	0	0	+	0	0	+	0	0

0 = no growth, + = optical density equivalent to controls, ++ = optical density higher than controls, ± = optical density less than 50% of control growth.

The non-ionic Tweens 20, 40, and 80 affected growth less than did the Igepals (Table 4). *Stichococcus* sp. GSB and *Nannochloris* sp. again appeared to be the most susceptible species and inhibition took place in all 3 Tweens at 0.01%. At 0.1% there was a difference in the growth response of the two species of *Chlorella* to Tween 20. Growth of *Chlorella* #580 was inhibited in Tween 40, and *C. stigmatophora* was inhibited in both Tween 40 and Tween 20. The non-motile unicells, *Protococcus* sp. and *Chlorococcum* sp. C, as well as all of the motile chlorophytes, were not inhibited by Tween 20, Tween 40, and Tween 80 in concentrations up to and including 0.1%.

Anionics. Organisms were arranged in 6 groups to correspond to the inhibition patterns found with the non-ionic detergents, and growth was plotted as % of control growth. However, only 3 inhibition patterns were evident with the alkyl aryl anionics. Except for *Protococcus* in T-77, there were two inhibition patterns with the alkyl-type anionics. With the alkyl aryl sulfonates, *Stichococcus* GSB and *Nannochloris* sp. were inhibited at the lowest concentrations, and *Protococcus* sp. at the highest; other species were intermediate (Fig. 7). A similar inhibition pattern was evident for all organisms in this intermediate group, where complete inhibition of growth took place in 0.01% ABS (0.0054% active) and in 0.1% BX-78 (0.08% active). *Stichococcus* GSB, *Nannochloris* sp., and *Protococcus* sp. were also tolerant of higher concentrations of BX-78 than of ABS.

Of the alkyl-type anionic agents, Conco Sulfate M was more inhibitory than the sulfonated amide, Igepon T-77. *Stichococcus* GSB and *Nannochloris* sp. were completely inhibited in 0.001% (0.0002% active) Conco Sulfate M. All other species exhibited the same type of inhibition pattern in Sulfate M in which growth did not occur at 0.01% (0.002% active). However, at lower concentrations there was a difference in the % inhibition, which was smallest for *Protococcus* and largest for the flagellates (Fig. 8).

The only surfactant not uniquely inhibiting *Stichococcus* GSB and *Nannochloris* sp. was Igepon T-77. With the exception of *Protococcus* sp. which it did not affect, all non-motile unicells were inhibited at 0.01% (0.007% active). The motile flagellates were more resistant and gave a similar response where growth was inhibited at 0.1% (0.07% active) (Fig. 8).

Cationics. Of all the surfactants examined, lauryl pyridinium chloride most extensively inhibited growth (Fig. 9). Even at 0.01% the growth of all the chlorophytes was inhibited and, indeed, only one species, *Chlamydomonas* sp., was not inhibited at 0.001%. Variation in species response was found at 0.0001%. Several non-motile species, such as *Chlorococcum* sp. C, *Stichococcus* GSB, and *Nannochloris* sp. were completely inhibited, but others, such as *C. stigmatophora*, *Chlorella* #580, and *Protococcus* sp. were not appreciably affected. Also, at this concentration the flagellates, with the exception of *D. euchlora* and *D. primolecta*, were not inhibited. These latter flagellates were extremely sensitive to this cationic detergent and even 0.00001% reduced growth 50% or more.

DISCUSSION

There were 6 different patterns of growth inhibition in response to the Igepal non-ionic detergents. With a single exception, species belonging to the same family had identical patterns, and each family exemplified one inhibition pattern. The exceptions were *Nannochloris* sp. and *Stichococcus* GSB. Although these two species are classified in different families (***32***), both had an identical pattern. This prompted an investigation into their identification. *Stichococcus* GSB was collected by Ryther (***29***), and tentatively identified as *Stichococcus*, probably, *S. cylindricus* (***4***) by Lewin, who used it to study vitamin B_{12} requirements (***20***). The possibility that it was not correctly identified was strengthened by the growth response to the non-ionic surface-active agents of a species identified as *Stichococcus bacillaris* in the Plymouth collection. This *S. bacillaris* resisted all the Igepal surfactants at the highest test concentration and, in fact, responded completely differently from the organism isolated by Ryther from Great South Bay.

The structure of the outer cell coat has been used in assigning species to families (***5,10***). Since surface-

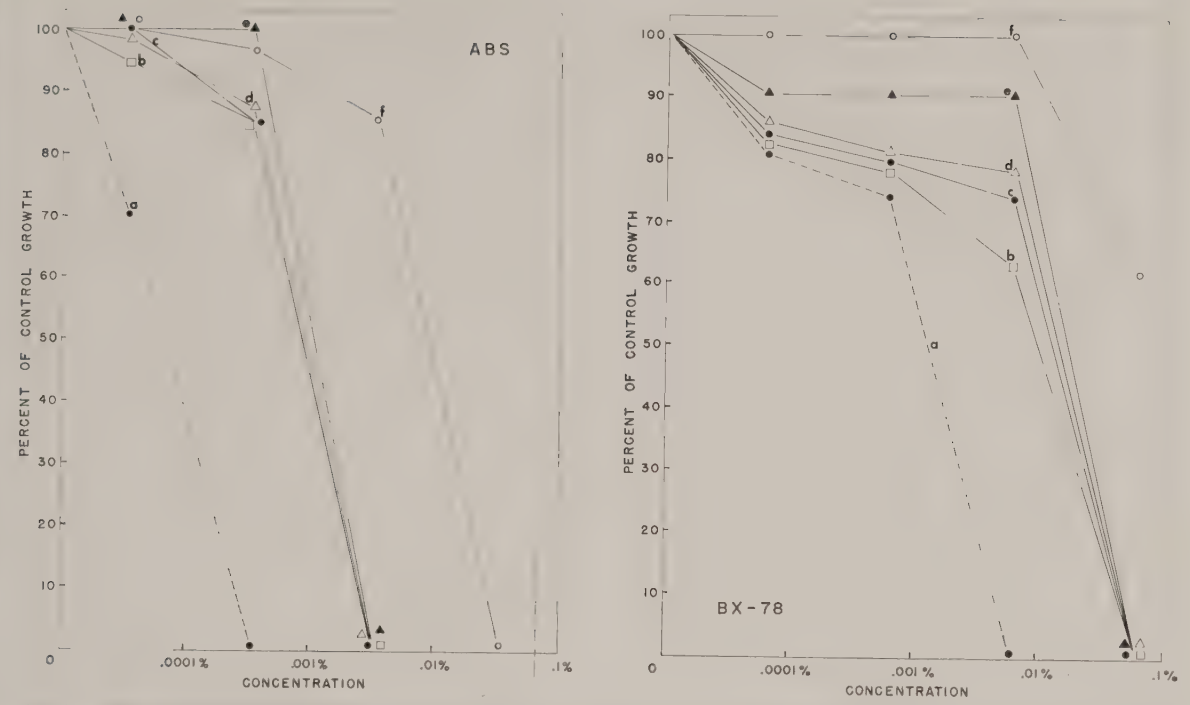


FIG. 7. Effect of the alkyl aryl anionic detergents ABS (left) and Nekal BX-78 (right) on the growth of: (*a*) *Stichococcus* sp. and *Nannochloris* sp.; (*b*) *D. euchlora*, *D. primolecta*, and *P. grossi*; (*c*) *Chlorella* #580 and *C. stigmatophora*; (*d*) *Carteria* sp., *Chlamydomonas* sp., and *Platymonas* sp.; (*e*) *Chlorococcum* sp. C; (*f*) *Protococcus* sp.

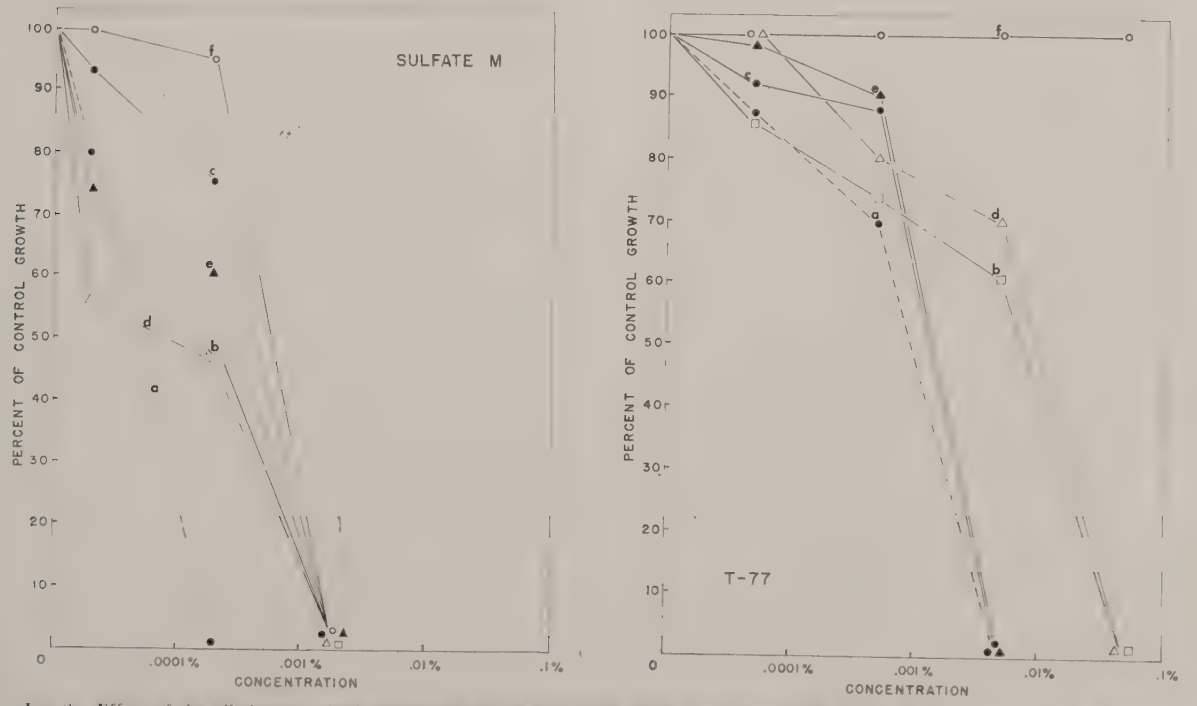


FIG. 8. Effect of the alkyl-type anionic detergents Conco Sulfate M (left) and Igepon T-77 (right) on the growth of: (*a*) *Stichococcus* sp. and *Nannochloris* sp.; (*b*) *D. euchlora*, *D. primolecta*, and *P. grossi*; (*c*) *Chlorella* #580 and *C. stigmatophora*; (*d*) *Carteria* sp., *Chlamydomonas* sp., and *Platymonas* sp.; (*e*) *Chlorococcum* sp. C; (*f*) *Protococcus* sp.

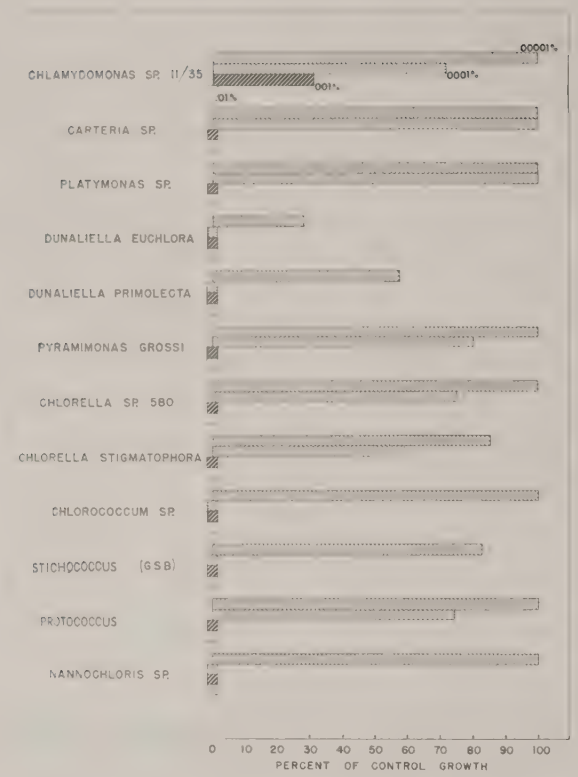


FIG. 9. Effect of the cationic detergent lauryl pyridinium chloride on growth.

active agents accumulate at interfaces, the outer cell coat must be important in response to surfactants. It is therefore likely that organisms with similar cell-wall characteristics respond similarly to surface-active agents. In some cases it seems as if the thickness of the cell wall helped protect against cell destruction. For example, *Protococcus* sp., the most resistant, was described as having a rigid thick cell wall (***10***). In contrast, the non-motile unicell, *Nannochloris* sp., was sensitive; species of this genus have no cell wall or one that is thin and smooth (***4***). The two species of *Chlorella* had an intermediate sensitivity. In this genus the cell wall is described as thin to intermediate in thickness, flat, and with no spines (***4,24***).

Although the morphological appearance of the cell wall seems to be important, it is not the only criterion involved in predicting a tolerance to surfactants. Although the Polyblepharidaceae were resistant to non-ionic detergents in the high test concentrations, they have an elastic periplast with no defined cell wall (***5***). However, growth of species in the Chlamydomonadaceae was inhibited in lower concentrations, although these species have a well-defined firm cell wall, often with a mucilaginous envelope (***5***). In addition to the gross appearance of the cell wall in terms of "thickness," the chemical composition could be important in bringing about a variation in species response to surface-active agents. The absence of cellulose from the cell wall of *Platymonas subcordiformis* (***21***) may be significant since, although *Platymonas* sp. was sensitive to the non-ionics, it is described as having a thick cell wall (***5, 10***). Two species of *Chlamydomonas* may also lack cellulose (***19***). A high content of lipids and proteins in the cell membrane and a preponderance of these components over cellulose in the cell wall could underlie the inhibitory effect of surfactants on algal species that have a "thick" cell wall. A high content of lipids in the wall would facilitate penetration of hydrophobic surface-active agents, and a high content of proteins would contribute to the destruction of the wall structure. Protein molecules unfold at water-oil interfaces with consequent destruction of structural and metabolically active protein elements. That this may account for the susceptibility of *Chlorella* is suggested in a report that lipid, cellulose, hemicellulose, and glucosamine, as well as an unusually high content of protein, are present in the cell wall of *C. pyrenoidosa*. The protein component in the wall may be structural in function, metabolically active, or both (***25***). The cell walls of several other *Chlorella* cells were analyzed; true cellulose was concluded to be only a small fraction of the cell wall (***3***).

With the non-ionic detergents, the more hydrophobic agents were more inhibitory. These findings are consistent with the hypothesis that hydrophobic molecules penetrate the cell more easily than hydrophilic agents (***13***). These observations are in accord with Jirgensons' thesis (***16***) that the efficiency of detergents at unfolding protein molecules at interfaces is due primarily to the lipophilic hydrocarbon chain. Presumably this is due chiefly to penetration of the hydrocarbon tail of the surfactant into the hydrophobic interior of the protein where it remains bound by weak cohesive forces. There are few reports of growth-promotions or inhibitions directly attributable to surface-active properties of surfactants, as was found with the non-ionic detergents examined.

Ionic agents may also interact with proteins by an electrostatic attraction or repulsion of charged groups on protein or lipoprotein of the surface ultrastructure. Because of the electric charge and the variations in chemical composition, as well as surface-active properties, results with anionic agents are more difficult to interpret. The pattern of inhibition in the anionic detergent, Nekal BX-78, applied to ABS, but with a difference in inhibitory concentrations. The benzene compound may have a greater effect on growth than the naphthalene agent, BX-78, because the ABS structure is smaller. The difference in the response of the two alkyl compounds may also relate to molecular size. Magnesium lauryl sulfate was more inhibitory than Igepon T-77, perhaps due to the greater penetrability of the smaller straight-chain molecule than the amide or the ring com-

pounds. In addition to these factors, experiments with non-ionics and cationics indicate that growth inhibition by anionics probably depends on their surface-active properties.

The cationic detergents are potent antibacterials and generally considered highly toxic (*11*). In this study the cationic surfactant was toxic at the lowest concentrations of the 3 classes of detergents. Since cationics hardly affect surface tension at low concentrations (*11*), stimulation or inhibition of growth must be due to other factors. A quarternary ammonium compound had a growth-depressing effect in low concentrations on the alga, *A. convolutus*, in the first 2 weeks, followed by a sharp increase due to a release of nitrogen (*39*). At higher concentrations the antibacterial action is attributed to the affinity of the cation for the negative charge on the bacterial surface. Two positively charged detergents affected the ability of *Paramecium aurelia* to migrate in an electric field, while anionics and non-ionics had no effect (*6*). The electrokinetic properties of algae are probably also responsible for the high sensitivity of of the chlorophytes to the cationics. Several species of algae remained electronegative through a wide pH range (*15*).

Armstrong (*1*) found that at inhibiting concentrations of cationics, phosphorus-containing compounds were lost by yeast. He therefore suggested that inhibition by cationics reflects disruption of the cell membrane. The greater sensitivity to cationics than anionics was postulated to depend on an interaction of surfactant cationic groups with anionic groups on the cell surface. As further evidence of the significance of the charge at the cell surface, Voss (*37*) noted that the bactericidal effectiveness of anionic agents was increased by divalent cations; he reasoned that the cations act by decreasing the negative charge at the cell surface, and that increasing the adsorption of surfactant anions leads to damage of the cytoplasmic membrane and death.

There is ample evidence that lowering the interfacial tension between outer cell coats and watery medium so alters permeability as to increase the rate of nutrients entering or leaving a cell. Various non-ionic surfactants increased the permeability of a fungus (*33*), and evidence has also been presented for increased permeability of the flagellate *Ochromonas danica* in the presence of anionic detergents (*34*). Further indications of effects on permeability were inferred in a report that alkyl sulfates inhibited induction of an enzyme in *Staphylococcus aureus* (*17*). Indirect evidence of surface destruction by non-ionic detergents was found in the ciliate, *Tetrahymena pyriformis*: it became extremely fragile and easily ruptured in non-ionic detergents (*18*)—which is consistent with the hypothesis that a radical destruction in the outer cell coats could lyse unicellular algae, and a partial disruption irreversibly change the permeability barriers of the cell. It seems reasonable to assume that the growth inhibitions induced by surfactants reflect differences in the outer cell coats of the algae studied.

The current use of large quantities of synthetic detergents contributes to the problem of the contamination of our natural bodies of water with the products of modern technology. The most widely used detergents, the alkyl aryl sulfonates, are generally considered resistant to biological degradation (*26,31*) although it has been shown that mechanisms do exist for metabolizing the component parts of the ABS molecule (*36*), and that a partial degradation of alkyl benzene sulfate does take place (*35*). It is not surprising that contradictory reports exist on its degradability, since ABS is a mixture of isomers and homologues: in the range C10 to C15, 80,000 isomeric alkyl benzene sulfonates are possible (*36*).

The apparent ABS levels in the surface waters show values ranging from 0.01 to 0.59 ppm for the Ohio River (*7*) and 3 to 6 ppm were reported in a British river (*12*). Because algae play a significant role in the aquatic food chain, the level of detergents found in nature becomes important. From the experiments it appears that ABS at 10 ppm only slightly inhibited most of the species tested with two exceptions where complete growth inhibition took place.

Since there is wide variation in the susceptibility of plankton species to detergents in water, some species may be destroyed while others survive. Such a variation in survival may not become apparent in total productivity measurements but, nevertheless, may be significant. Phytoplankton constitutes an important source of food for filter-feeding invertebrate larvae, and there is a relative food specificity for various stages of the life cycle (*8,38*). Chrysomonads, e.g., *Monochrysis lutheri, Isochrysis galbana, Dicrateria* sp., and *Pavlova gyrans*, that constitute very good foods for oyster and clam larvae, are inhibited by surfactants in concentrations lower than those tolerated by most of the chlorophytes (unpublished data). Such a selective species disappearance could importantly affect invertebrate populations.

Extrapolation of laboratory data to field conditions must be approached with caution. Formation of aggregates of detergents at high concentrations changes physical properties due to the formation of colloidal micelles, and the presence of electrolytes in the water is likely to promote micelle formation. Killing concentrations in electrolytes were lower than those in distilled water and salts of bivalent metals were more effective than univalent metals in protecting against cell lysis by cationic detergents (*2*). Another variable affecting toxic levels in natural situations is the variety of impurities and fillers included by various manufacturers. Stimulation of algal growth and triggering of blooms may be caused by phosphate fillers in commercial products (*7*), and

it was reported that the thiophosphate in commercial detergent preparations was responsible for growth stimulation of *Chlorella* (*23*).

The mechanism of action of surfactants must be understood in the laboratory for valid analyses of natural situations. The large number of synthetic detergents now available presents an unusual opportunity for studying the effects of surfactants on systems of biological interest and appear to be especially suitable for studies of the cell surface.

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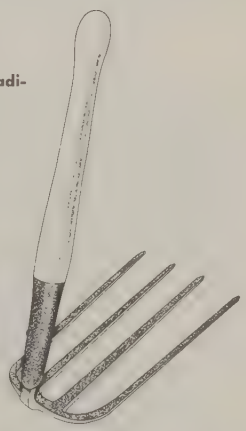
THE SOFT-SHELL CLAM . . . A RESOURCE WITH GREAT POTENTIAL

The Soft-shell Clam, *Mya arenaria*, is found from Labrador to North Carolina on the U.S. East Coast, and in a number of scattered locations on the West Coast. The East Coast has two centers of abundance: Maine to Massachusetts in the north and Chesapeake Bay in the south. In the north, most populations are intertidal, although some are subtidal. In Chesapeake Bay, nearly the entire resource is subtidal.

New England Clam Production Declined

In New England, this clam has been used for food or groundfish bait since colonial days. It is now marketed principally as fresh, shucked meats; but is also sold in the shell or canned. The fishery is public and unmanaged. Most clams have been harvested in the intertidal zone with hand hoes or forks, and this hand digging destroys about 50 percent of the clams left behind. Between 1948 and 1964, New England's annual production has fallen from about 900,000 to 200,000 bushels. The decline, however, has been checked and the take is rising slightly. The recent decrease in Green Crab (*Carcinus maenas*) predation has permitted clam stocks to increase; however, the landings may not increase proportionately because more clam areas are polluted and consequently closed each year. Markets and price may also limit production.



New England clam diggers using the traditional hoe (insert).

MARINE RESOURCES OF THE ATLANTIC COAST

Leaflet Number 3, October 1965

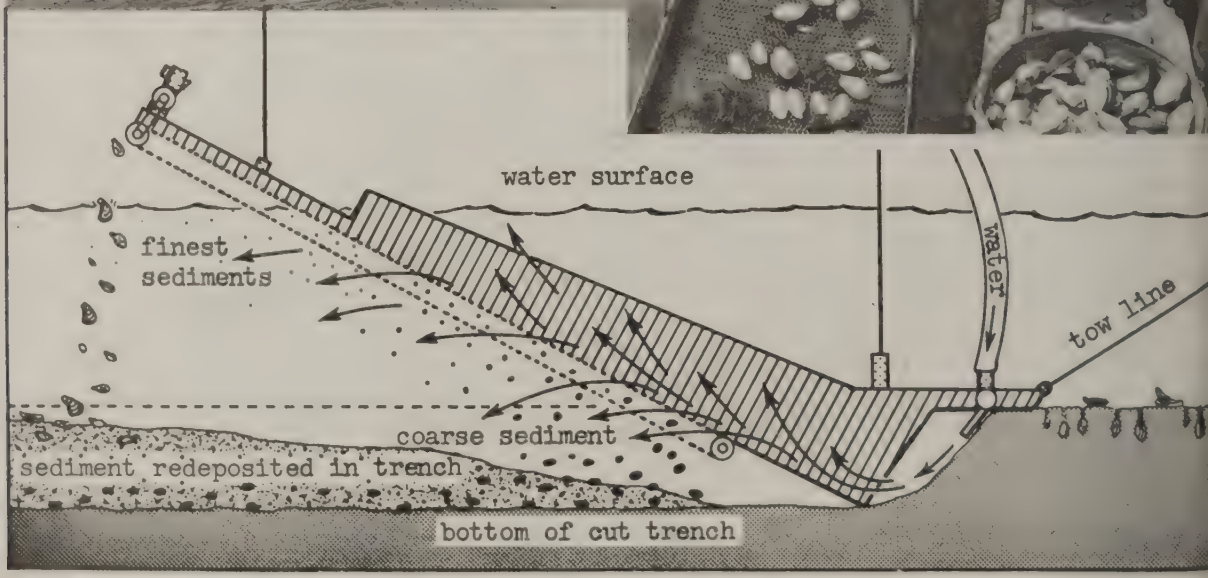
ATLANTIC STATES MARINE FISHERIES COMMISSION, 336 East College Avenue, Tallahassee, Florida 32301

Chesapeake Bay's New Industry

In the relatively new industry in Chesapeake Bay, hydraulic dredges harvest the subtidal clams. This new gear enables the clam industry to use previously neglected stocks. Prior to 1951, clams were hand-dug and eaten only occasionally by Chesapeake Bay inhabitants, who call them "manninose." Until recently, the industry grew phenomenally. The present check in growth is due to economic, not biological, factors. Without the development of additional markets for the clam, the fishery will probably remain fairly stable. In Maryland, dredging is now permitted in portions of six counties. Restrictions not only limit where a clam dredger may operate, but also impose a 40-bushel limit per day per boat. About 150 licensed dredgers now produce approximately 700,000 bushels of clams annually. Only a small percentage of this production is used in Maryland; most is shipped to other States. The Soft-shell Clam fishery is now recognized as a major seafood indust in Maryland.

Life History Varies Geographically

Spawning may take place in June-August in northe Maine and during July-September in Massachuse north of Cape Cod. In Chesapeake Bay, two reprodu tive cycles occur each year and spawning may occur May-June and again in September-October. The sex are separate, fertilization is external, and the larv are planktonic for 2 weeks or more, depending upo temperature. Maine larvae develop normally at ter peratures of 10°-25°C. and salinities of 15 °/oo a over. Chesapeake Bay larvae develop normally in t same temperature range, but at salinities of 10 °/ and over.



Larvae, juveniles, and adults feed upon microscopic plankton which they filter from the water. Naked flagellates appear to be of great importance as food, especially to the larvae.

When the larvae have developed sufficiently they metamorphose to adult form and settle to the bottom. There they may temporarily attach by byssal threads to the sediments. A juvenile clam may wander about, using its muscular foot, or be carried by currents until it is nearly an inch long. It generally establishes a permanent burrow in the bottom when 1 inch long and only digs deeper as it grows.

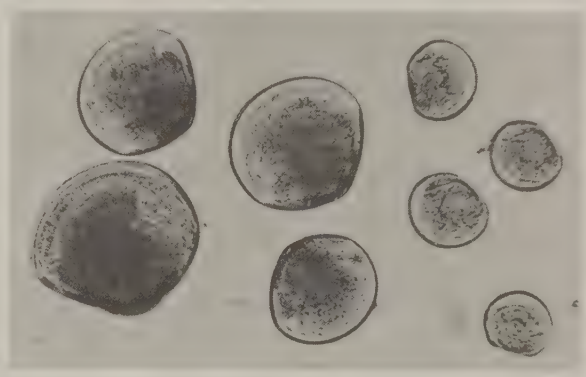
Growth varies widely and may be influenced by water currents, food supply, temperature, and nature of the sediments. A clam may grow to 2 inches in less than 2 years in Chesapeake Bay, in 3 years in favorable locations in Maine, or may never reach 2 inches in unfavorable locations.

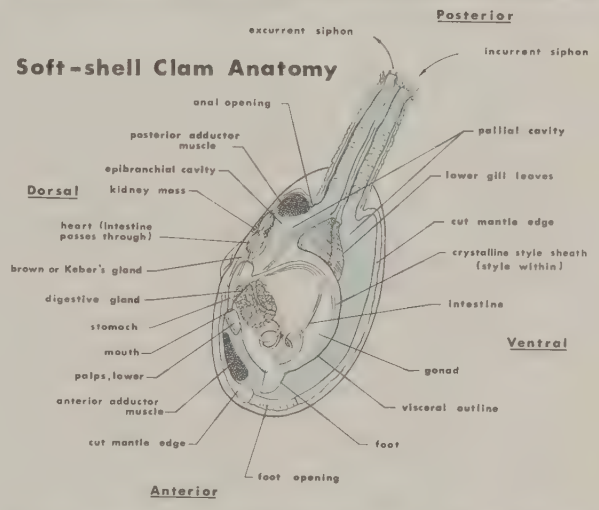
Clam Predators Are Many

This clam is a favored item of food for many animals; consequently, it is subject to extremely serious predation. Recently, the most serious predator in northern waters has been the Green Crab, which has depleted clam stocks in Massachusetts and Maine since the late 1940's. Other predators that can be locally serious are drills, the Horseshoe Crab, sea gulls, various ducks, and flounders and other bottom-feeding fish. Mass mortalities of clams not due to predators or shifting sediment, have been known to occur but remain unexplained. In the Chesapeake, great numbers of Cow-nosed Rays feed on clams during the summer. Unusually high water temperatures may cause heavy mortalities in local areas. The over-wintering populations of Whistling Swans and ducks depend on Soft-shell Clams for food.

Research Covers Many Aspects

Green Crab predation in New England stimulated life history studies on this crab by the Bureau of Commercial Fisheries. Methods of crab control by means of fences and chemical barriers were developed and tested by the Bureau and the Maine Department of Sea & Shore Fisheries. The Bureau also studied and described the reproductive cycle of the clam in New England and Chesapeake Bay; has developed laboratory techniques for spawning and rearing clam larvae;





Soft-shell Clam larvae (upper) are similar to those of other bivalves. The largest of the stages shown is smaller than a fine sand grain. The Green Crab (below) is the principal clam predator in New England.

The research vessel *John A. Ryder* is equipped with the Maryland hydraulic esculator dredge (upper left). A closeup (upper right) and the schematic drawing (below) show the essential parts and operation of this dredge.

and has determined some salinity and temperature requirements of larvae and juveniles. Maine is investigating the acclimation of adult clams to various salinities; is studying the ever-increasing problem of using large stocks of polluted clams; and has a pilot plant project on ultra-violet sterilization of water for self-cleansing of the clams. This cleansing process, depuration, is now in limited commercial use. The State of Maryland has studied effects of hydraulic dredging upon the bottom and on clam populations in particular; has made observations on spawning and setting behavior in the relatively warm waters of Chesapeake Bay as compared with those in the cooler waters of New England; and is studying the yearly cycle of condition of Maryland clams living in various salinities. Canada has recently been developing a semi-mechanical method of harvesting the clams in shallow water. In Massachusetts, private organizations are studying clam culture in ponds under partially controlled conditions.

Supply Is Greater Than Demand

In both New England and Maryland the most serious immediate need is to expand markets for the clam. Obviously, the clam supply is exceeding the demand. In Maryland the boats operate on a daily catch quota, and the price per bushel has dropped from $4.00 to as low as $2.00. The present average price to the dredger is about $2.75. In Chesapeake Bay, the clams are widely distributed and population densities are highly variable. The size of the present resource is enormous: a fraction of the total area of tidewater bottoms is estimated to have a harvestable standing crop of more than 1 million bushels.

Many Problems Remain Unsolved

Pollution of the costal region, particularly of fishery areas, is a challenge for all of us. In New England and the Middle Atlantic States other basic problems are: How to place the resource in the hands of those who can handle it best? How best to obtain natural sets in desired locations where the clams will grow and survi to market size? How to develop and apply efficie harvesting methods and to stabilize the supply? How t develop quality standards and stimulate industry t maintain quality throughout the entire range of produc tion, distribution, and processing of present and ne products?

Our knowledge of the Soft-shell Clam and i environment still has wide gaps. Much more study needed on life history and ecology. Work on cla physiology should be expanded because of its dire value in developing techniques for culture, manag ment, and self-cleansing.

A Great Potential Exists

The potential of the clam resource is tremendou We are dealing with a source of food close to the botto of the food chain, and tons of valuable protein can b produced from relatively small areas. With develop ment, proper environmental control, and careful man agement, clams have the biological potential to suppor a greatly increased sustained production.

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Research Notes

A method for preserving color in biological specimens

The loss of natural color in biological specimens is a problem to many biologists. Precise color notes and color photography can provide some solution but present many disadvantages to the field collector. Obviously, the preservation of color in the specimens themselves would be the best solution. A chemical antioxidant, Butylated Hydroxytoluene [1] (BHT), has been found quite effective for this purpose. This substance was tested in response to a suggestion by Mrs. Mary H. Thompson, a chemist at the Bureau of Commercial Fisheries Technological Laboratory in Pascagoula, Mississippi.

Initial tests with crystalline BHT, which is insoluble in formalin, gave promising results. When the substance was added to fish specimens freshly preserved in formalin, color was retained, but only in those spots where crystals adhered to the body surface.

Subsequent tests with a 40% emulsifiable concentrate of BHT (a liquid), which mixes readily with both formalin and alcohol, gave quite satisfactory results. The work was done largely on board the Bureau of Commercial Fisheries Exploratory Fishing Vessel OREGON during the summer of 1963.

The BHT was tested on a variety of orange- and red-colored fishes trawled from depths of 200 fathoms off the Dry Tortugas. Immediately after capture, each species was sorted into groups of similar color and tone, and each group divided into four lots. Three of the lots from each group were then placed in separate glass jars containing 1, 10, and 20 cc of BHT concentrate per 4500 cc of 10% formalin. The fourth lot was preserved as a control in 10% formalin without BHT. The jars of specimens were then exposed for a week to the effects of direct sunlight and tropical temperatures.

Superior color retention in the specimens treated with BHT soon became apparent and has persisted. The specimens in formalin without BHT showed an obvious color loss within a matter of hours. Within the one-week period they became almost entirely pallid, while those with BHT retained their color markedly, but to varying degrees that corresponded to the different concentrations used. At the present time, 18 months later, the specimens preserved in formalin without BHT completely lack their original orange and red colors, whereas the coloration of those in the strongest concentration of BHT is very similar to what it was when they were caught.

The species involved were: *Paraholl-ardia schmidti* Woods, *Setarches guentheri* Johnson, *Trachyscorpia cristulata* (Goode and Bean), *Helicolenus dactylopterus* (De La Roche), *Callionymus agassizi* Goode and Bean, and an unidentified species of *Peristedion*.

Other tests with BHT, performed from time to time on various fish specimens, have yielded equally good results whenever red, orange, yellow, brown, or black colors were involved. A single test on a blue damsel fish resulted in only partial retention of that color. Fishes with colors other than the above have not been tested. The antioxidant has been ineffective, however, in retaining iridescent lusters, which were prominent in some flying fishes, a juvenile sailfish, and a juvenile snake mackerel. In a few instances when BHT was used with 40% isopropyl alcohol as a fixative, the results were comparable to those obtained with formalin.

From a similar study dealing with the preservation of color in fish specimens, Yoshida (1962) has reported good results with sodium ascorbate, which is an antioxidant in the pH range he employed (Pottinger, 1951).

Several biologists who have learned of the preliminary results reported here are now making detailed studies of BHT as a color preservative. Considering the successful application of BHT and sodium ascorbate and the wide variety of other antioxidants now available, the possibilities of further progress in this area seem bright.

Addendum

Since this note was submitted, we have seen a report by Toyama and Miyoshi (1963. Prevention from color fading of aquatic animals under preservation — I. *Jour. Tokyo Univ. Fish.*, **50**[1]: 43-48) on the effectiveness of BHT and two other antioxidants (Butylated Hydroxyanisole [BHA] and Na-Erythorbate [ERB]) for retaining the red coloration of a snapper (*Etelis carbunculus*) and a prawn (*Pandalus borealis*), preserved in 10% formalin. Their results with the snapper appear excellent using a flake form of BHA (SUSTANE 1), which "well retained the original color even five months later." In contrast, snapper specimens treated with crystalline BHT (SUSTANE BHT) and an undetermined form of ERB lost their color after only 30 days. The poor results they obtained with crystalline BHT on the snapper were likely due to the same insolubility problem we experienced with the compound. In experiments with the prawn, BHT provided better color retention than did the other antioxidants and their synergists.

Richard A. Waller, *Bureau of Commercial Fisheries, Washington, D.C. and* William N. Eschmeyer, *Institute of Marine Science, University of Miami, Miami, Fla.*

Acknowledgments

Thanks are due Drs. J. Lockwood Chamberlin and William J. Richards, Bureau of Commercial Fisheries, Washington, D.C., and C. Richard Robins, Institute of Marine Science, for critical review of the manuscript.

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(Contribution No. 597 from the Marine Laboratory, Institute of Marine Science, University of Miami.)

[1] Manufactured by the Shell Chemical Company, under the trade names IONOL CP (crystalline) and IONOL CP-40 (40% emulsifiable concentrate). Samples for this study were kindly furnished by the Shell Industrial Chemicals Division, New York 20, New York.

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Reprinted from TRANSACTIONS OF THE AMERICAN FISHERIES SOCIETY
Vol. 94, No. 3, July 1965
pp. 267–268

A Technique for Mounting and Storing Herring Otoliths

INTRODUCTION

The validity of the otolith method for aging Maine herring, (*Clupea harengus harengus*, Linnaeus), has been reported earlier (Watson, 1964). The morphology and analysis of herring otoliths are discussed at length in that paper. The otoliths are analyzed by placing them, distal (outer) surface upward, on a dark surface in reflected light. They are small (2–4 mm) and brittle, and since they are easily fractured by finger pressure, a minimum of handling is desirable.

In beginning my studies, I used Lissner's (1925) method for storing otoliths; this merely involved placing them in small vials. Lissner's method is eminently suited to small collections of a few thousand otoliths; the chief drawbacks are the relatively large storage space required and the time one loses in moving the otoliths to and from their vials for analysis. When my collection of otoliths reached 30,000 pairs, it became necessary to devise a more efficient technique for mounting and storing the specimens. This report describes that method; while it was designed primarily for the herring, the method can be adapted to other species.

MATERIALS AND METHODS

Black Plexiglas[1] No. 2025, 3/16-inch thick, with a nonreflecting finish (F-10) on one surface, is the basic material. Plexiglas is sold in stock sheets measuring 4 feet by 6 feet. Allowing for waste, one can cut 144 blocks measuring 5¾ inches by 3¾ inches, a size suited to most microscope stages, from a stock sheet. Fifty circular depressions ⅛-inch deep and 15/32 inch in diameter are cut into the dull surface of each block with a double-fluted cove box bit operated at low speed, about 300 rpm; if the depressions are spaced about ⅛ inch apart in five rows of 10 each, a blank strip ¾-inch wide will be left for labeling (Figure 1).

Otoliths are excised, dried, and placed distal surface upward, one pair in each depression. A constant pattern of arranging the otoliths is obviously necessary; it is convenient to number the first depression in each row and proceed from left to right when placing the otolith pairs. Plexiglas is easily marked with a diamond-tipped scribe. To avoid excessive handling, the otoliths are best manipulated into position with a small brush.

The otoliths are fused permanently into their depressions with ethylene dichloride. Ethylene dichloride is a chlorinated hydrocarbon and should be used with care; its physical and chemical properties are described in the Merck Index (Stecher, 1960), and general safety precautions suited to its volatility and flash point must be observed. When the depressions have been filled with otolith pairs, a No. 27 hypodermic needle and *glass* syringe are used to flow a drop of

FIGURE 1.—Fifty pairs of herring otoliths mounted in Plexiglas.

the liquid under each pair. (Plastic throw-away syringes are dissolved by ethylene dichloride). In 5 to 10 minutes the solvent will evaporate completely and leave the otoliths permanently fused in their depressions. The fusion will withstand a severe jarring.

Ethylene dichloride is a solvent cement; it leaves the otolith unaffected while attacking the Plexiglas substrate to form a cement cushion that, upon drying, makes the otolith an integral part of the block. Only the minimum amount of ethylene dichloride delivered by the syringe is necessary to fuse the otoliths in place. If the depression is flooded with ethylene dichloride, the whole specimen may be coated with dissolved substrate, making it impervious to moisture. One-half cc of ethylene dichloride will fuse 50 otolith pairs. As soon as the bond is dry, the otoliths may be soaked in water for analysis and then dried with a lint-free tissue. Repeated soakings and dryings do not affect the cement bond. Ninety-five per cent ethyl alcohol may be used sparingly to moisten herring otoliths. For age determinations, alcohol brings out the zoned structure more quickly, though not more intensely, than water. Fractured otoliths may be positioned and cemented in the same manner as entire specimens. An otolith can easily be removed from its mount, should that become necessary, by flowing a drop of ethylene dichloride into the depression. In a minute or 2 the bond will dissolve and the otolith can be lifted out.

Sample data can be recorded upon a tape placed across the base of the block.

RESULTS AND DISCUSSION

The mounting technique described in the foregoing offers considerable advantages over the use of vials to store otoliths. For herring otoliths, use of the method has effected an 85 per cent reduction in analysis time, a 75 per cent reduction in cost of materials, and a 95 per cent reduction in storage space. The danger of breakage is eliminated.

Cements for Plexiglas are of two general types: solvent and polymerizable cements. Ethylene dichloride, as has been noted, is a solvent cement. Other solvent cements that may be used with herring otoliths are methylene chloride and a mixture by volume of 90 per cent methylene chloride and 10 per cent diacetone alcohol.

The chief problem in cementing Plexiglas to a dissimilar material is that differences in thermal expansion place a stress upon the cement bond. The herring otolith–Plexiglas bond formed by ethylene dichloride was tested in the 40 to 100 F range and found to hold securely. The area of attachment between the double-ridged proximal surface of the herring otolith and the Plexiglas is very small and enhances the strength of the joint by limiting the area of thermal stress. If the technique described here were used to mount otoliths requiring a large area of attachment, the soft bond formed by the solvent cement 1,1,2-Trichloroethane (vinyl trichloride) might be worth testing.

The polymerizable cement Acryloid B-7 formed a strong bond between the herring otolith and the Plexiglas, but required a half-hour to set and was rejected in favor of the quick-acting solvent cement. Care had to be taken to coat *only* the two surfaces to be joined with Acryloid B-7, but that presented no serious obstacle. Acryloid B-7 would be well worth testing if one wished to mount large otoliths. In experiments with herring otoliths, I found it most convenient to place a small drop of Acryloid B-7 in the bottom of the depression and to set the otoliths in position with jeweler's tweezers.

[1] Trade names referred to in this publication do not imply endorsement of commercial products.

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Made in United States of America
Reprinted from TRANSACTIONS OF THE AMERICAN FISHERIES SOCIETY
Vol. 94, No. 4, October 1965
pp. 382–385

Observations on the Swimming Ability of Adult American Shad (*Alosa sapidissima*)

CHARLES R. WEAVER

Observations on the Swimming Ability of Adult American Shad (*Alosa sapidissima*)

INTRODUCTION

For several years the Bureau of Commercial Fisheries, under contract with the U. S. Army Corps of Engineers, has been investigating various factors influencing the behavior of adult salmonids in relation to fish passage problems on the Columbia River and its tributaries (Collins and Elling, 1960). In the course of these investigations, incidental observations were made on the American shad (*Alosa sapidissima*) which utilized the same waterways as the salmonids. Observations presented in this report were made during the period of 18 to 28 July 1961.

The objective of the primary study on salmonids was to gain further knowledge of the maximum water velocities that could be negotiated. The presence of shad during the experiments, however, also made it possible to obtain information on the swimming ability of this species. Specifically, this report covers the channel distances negotiated by the American shad in water velocities ranging from 11.4 to 13.6 feet per second.

Although velocities of this magnitude may not often be encountered by American shad ascending the rivers and fishways at existing dams, a knowledge of their swimming ability in these higher velocities is meaningful. The continuing effort to develop more efficient and economical fish passage facilities in the Columbia River drainage requires a thorough knowledge of the physical requirements and swimming abilities of the various species of fish involved.

Even though American shad in the Columbia River are not at present regarded with the

FIGURE 1.—View of introductory area and channel during the 11.4-foot-per-second velocity tests.

same esteem as salmon and trout, large numbers of these fish ascend this drainage annually, and they must be considered in the design and operation of fish passage facilities that may be utilized by them. By the same token, information on the swimming abilities of American shad may be of use on the East Coast, where efforts are currently under way to rehabilitate shad runs by providing passage to production areas that have been lost due to dams or other resource developments.

METHODS AND MATERIALS

The observations were made at the Fisheries–Engineering Research Laboratory at Bonneville Dam on the Columbia River. The laboratory is basically a large tank, approximately 181 feet long by 24 feet wide, located on the right bank of the river adjacent to the Washington shore fish ladder. The fish enter and pass through the laboratory via short fish ladders connected with the Washington shore fish ladder. Passage is volitional, and the fish are not handled at any time.

The arrangement of the laboratory during these experiments was the same as that employed in earlier velocity experiments conducted in 1957 (Weaver, 1963). Testing facilities for fish consisted of a channel 85 feet long by 5 feet wide (Figure 1). The velocity of the flow in the channel was regulated by the slope of the channel floor and the head on the channel. Four different velocity conditions were tested. Average velocities during the tests, based upon measurements taken at the downstream end of the channel, were 11.4, 12.6, 13.2, and 13.6 feet per second. More extensive measurements made within the channel after the tests were completed revealed that velocities were generally somewhat lower (up to 1 foot per second) in the upper reaches of the channel. Depths of water in the channel were 2.1, 1.8, 1.8, and 1.6 feet, respectively, for the above velocity conditions.

Normally, tests were made in the channel by releasing individual fish into the introductory area (Figure 1). As they moved upstream through the channel, the fish were followed by observers stationed on walkways above. Although some of the American shad observed during these experiments entered the laboratory in this manner, a larger number entered by drifting downstream from the main fish ladder through the exit ladder of the laboratory. After entering in this fashion, the shad continued downstream through the test channel, and accumulated in the introductory area. Even though there were areas where these fish could remain in relatively calm water, they were continually entering the test channel and attempting to swim back upstream. The observations of swimming ability presented here consist of the distances which the shad attained in these attempts to negotiate the channel.

The water velocity in the channel was reduced at the end of each day to give shad, accumulating in the introductory pool, the opportunity to pass through the channel and leave the laboratory. Although many shad were noted swimming up the channel when the flow was reduced, they seemed to have no great desire to leave the laboratory and

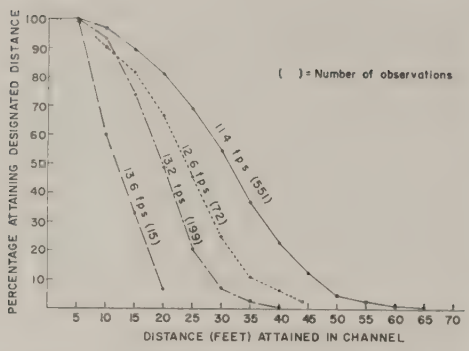

FIGURE 2.—Performance of shad in flows of 11.4, 12.6, 13.2, and 13.6 feet per second. Data are plotted at 5-foot intervals.

TABLE 1.—*Distances attained by shad in flows of 11.4, 12.6, 13.2, and 13.6 feet per second*

Water velocity ft/sec	Date	Water temperature (F)	Number of observations	Distance attained	
				Mean (feet)	Maximum (feet)
11.4	July 21	70	62	27.2	54
	22	70	193	29.2	59
	23	70	160	32.0	65
	24	69	106	30.5	63
	25	69	30	29.9	60
	Total		551	30.1	65
12.6	25	69	18	19.1	41
	26	69	29	24.8	43
	27	69	25	24.8	44
	Total		72	23.4	44
13.2	18	70	72	18.8	35
	19	70	127	18.8	40
	Total		199	18.8	40
13.6	28	69	15	11.7	20

return to the Washington shore ladder. Each morning shad were present in the flow introduction pool (upstream end of the channel). As soon as the velocity was increased, they began falling back downstream through the channel. It is believed that some of these fish remained in the laboratory for several days and could have contributed to daily observations.

The upstream and downstream movement of shad in the laboratory was similar to their general behavior in the Washington shore ladder during the same period. Although large numbers of shad could be observed in the ladder pools and considerable to-and-fro movement was evident in the fishway, few shad were being counted out of the ladder at the upstream end. It is believed, however, that even though many shad did not continue their movement upstream through the ladder, this phenomenon was due to something other than a lack of ability to negotiate the ascent. Similar upstream–downstream passage was reported by Talbot (1953) and also noted by Bell and Holmes (unpublished) while studying the passage of shad in the fish ladders at Bonneville Dam.

The American shad observed in this study were from the latter part of the run, and it is possible that some had reached sexual maturity and were preparing to spawn in the ladder pools. The peak of the migration had occurred during the first week of July. At this time, counts at the upstream end of the Washington shore ladder exceeded 10,000 shad per day. When these observations on shad were in progress, counts averaged less than 200 fish per day.

RESULTS AND CONCLUSIONS

The distances attained by shad in their attempts to ascend the channel varied inversely with the velocity of the flow (Figure 2). Mean distances attained by groups of fish tested in the four velocities ranged from 11.7 feet in the 13.6 ft/sec velocity to 30.1 feet in the 11.4 ft/sec velocity (Table 1). None of the shad negotiated the entire 85-foot channel. Maximum distances attained ranged from 20 feet at 13.6 ft/sec to 65 feet at 11.4 ft/sec.

Considering the possibility that many of these observations may have been made when the shad were in a weakened or declining physical condition (from repeated exhaustive swimming efforts or factors associated with spawning), performance levels shown may be somewhat less than would have occurred under more favorable circumstances. Although shad appear to be capable of swimming modest distances in relatively high velocities, even the lowest of the four velocities tested might present a serious barrier for some shad if a passage of more than a few feet were required.

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Density-Dependent Food Relationships With Reference to New England Groundfish.

BY ROLAND L. WIGLEY

Reprinted from
International Commission for the Northwest Atlantic Fisheries
Special Publication Number 6, 1965.

Reprinted from
International Commission for the Northwest Atlantic Fisheries
Special Publication Number 6, 1965.

C-7

DENSITY-DEPENDENT FOOD RELATIONSHIPS WITH REFERENCE TO NEW ENGLAND GROUNDFISH

By

Roland L. Wigley[1]

ABSTRACT

From the ecological standpoint, food webs and the quantitative aspects of major pathways in food webs are exceedingly important because of the fundamental and comprehensive influence of nutrition on individual organisms. Many of the population attributes fishery biologists are concerned with, such as survival rate, growth rate, length-weight relationship, age composition, sex ratio, fecundity, migration, density distribution, are all profoundly affected by nutrition.

Contagious distributions are characteristic of animal populations; New England groundfish, haddock in particular, provide good examples of this type of distribution. Food is a major element in attracting animals to particular places.

Past research has neglected the quantitative relationships between groundfish stocks and their food supply. Preliminary data presented here indicate that groundfish on the New England Continental Shelf congregate in specific geographical areas. Furthermore, macrobenthic invertebrates — a major source of groundfish food — tend to be aggregated in the same localities. It is suggested that more intensive studies of this subject may provide some of the information necessary to understand the present biological status of, and prognosticate future changes in, groundfish abundance, growth, distribution, size composition, and other population attributes.

INTRODUCTION

In ecological investigations the importance of food and feeding cannot be overemphasized. According to Borradaile (1923) "Relations between an animal and other organisms in its surroundings are almost always based in the long run upon nutrition". Even the reproductive process is reduced or ceases when nourishment falls to substandard levels. Nourishment for each individual must be obtained from its environment, and there is obviously a limit to the quantity of food the environment can produce. It follows, then, that food can be a major influence governing population size and composition.

It is the purpose of this report to call attention to the ecological importance of foods, review some of the density-dependent food relationships, and discuss some preliminary results of food concentrations in relation to the density of New England groundfish.

In this report a food shortage is considered the converse of too many predator animals. It is the absolute shortage of food (or the relative density of consumers versus food) that is relevant to this topic.

POPULATIONS LIMITED BY FOOD SHORTAGES

Good evidence exists to indicate that food shortages are effective in limiting the population size of certain animal species. This phenomenon has been observed in representatives of various animal groups, and undoubtedly numerous unstudied species are similarly restricted. Insects such as sheep blowflies, *Lucilia* and *Chrysomyia*, and flour-beetles, *Tribolium*, have been shown to have their numbers restricted by food shortages (Ullyett, 1950; Park, 1948; Park and Frank, 1950). Bird populations are likewise limited by food (Lack, 1954).. Large mammals, for example mule deer and white-tailed deer, *Odocoileus*, elk, *Cervus*, and other large ungulates, have been reported as being limited by food shortages (Leopold, 1943; Doman and Rasmussen, 1944; Raush, 1950; and Krefting, 1951). Food shortage is also one of the principal factors restricting populations of small mammals, such as voles, Cricetidae, squirrels, *Sciurus*, hares, *Lepus*, and foxes, *Alopex*, (Dice, 1952; Elton,

[1] U.S. Department of the Interior, Fish and Wildlife Service, Bureau of Commercial Fisheries Biological Laboratory, Woods Hole, Massachusetts, USA.

1942). Even the human population has been strongly influenced by food limitations. Primitive man is believed to have been held in check by food shortages, or his ability to obtain food (Andrewartha 1961). Famines and food-motivated emigrations by modern man during the early historical period and even in more recent times in Ireland and China (Carr-Saunders, 1922; Lack, 1954) provide further evidence of the vital influence food supplies have on the survival of human beings.

More pertinent to our topic are population limitations of aquatic organisms, particularly fish, resulting from food shortages. In addition to fluctuations in numbers of fish (survival rate) in relation to food supplies, other manifestations of food-related limitations are: (a) growth rate, (b) length-weight ratio, (c) fecundity, and (d) migrations.

The relatively recent entry of the sea lamprey *Petromyzon* into the Great Lakes provides a good example of changes in population abundance (survival rate) resulting from quantitative changes in food supply. Before sea lampreys were present in the upper Great Lakes, the lake trout *Salvelinus* - principal source of lamprey food - were plentiful. Lake trout landings amounted to millions of pounds annually in both Lake Huron and Lake Michigan. Several decades later the lamprey population had increased greatly whereas the trout population had been reduced to virtual extinction. This forced the lampreys to switch to alternate food sources, which consisted of several species of chubs, *Leucichthys* and whitefish, *Coregonus* and *Prosopium*. Subsequently the abundance of these species was severely reduced, some to near extinction. During the latter phase of this cycle a pronounced decline in number of lampreys became evident (Applegate, 1950; Erkkila, *et al.*, 1956; Moffett, 1958). If effective control measures had not been instituted by Federal and State (Provincial) agencies, the establishment of a numerical balance between the lampreys and their host species would have been expected.

Inasmuch as many kinds of fish are capable of surviving rather extended periods with little or no food, the short-term effect of food shortage is not necessarily a high mortality, but rather a retardation in growth. Brown (1957) states "Food supply is probably the most potent factor affecting the growth of fishes..." Thus, growth rate measurements may sometimes be useful in predicting low food supplies and subsequent limitations in fish abundance and fish production. For example, the average weight of individual sockeye salmon, *Oncorhynchus* in Cultus Lake, Canada, was reduced one half when the number of salmon was increased threefold (Foerster and Ricker, 1941). This example illustrates growth retardation resulting wholly or in part from food limitations. Numerous other reports in the literature indicate stunted populations of fishes, notably yellow perch, *Perca*, and bluegill sunfish, *Lepomis*, in situations where severe food competition exists (Carlander, 1950; Clarke, 1954).

Spectacular increases in growth rate of trout, salmon, and other species, after migrating from nursery streams to lakes or the sea results, at least in part, from richer food supplies. Migrations motivated by food requirements will be discussed in a later section.

Low fecundity among animals due to inadequate nourishment may be considered to have general application. According to Brody (1945), "... there is no doubt that egg production is related exponentially to feed consumption..." This is a well established principle heeded by agriculturists and fish culturists, and pertains to both domestic and wild populations. The effect of nourishment on fecundity in animals other than fish, for example birds and mammals (Lack, 1954; Cheatum and Severinghaus, 1950) has been adequately demonstrated.

In regard to fishes, Nikolsky (1963) reported, "The fecundity in a single population may undergo considerable fluctuations in relation to the supply of nourishment." In this same report he cites evidence of this relationship in two species, the humpback salmon, *Oncorhynchus*, and the roach, *Rutilus*. Information from other sources (Brown, 1957; Lagler, *et al.*, 1962) concur that "condition" and "environmental and physiological conditions" influence fecundity in fishes.

AGGREGATIONS OF ANIMALS SEEKING FOOD

An overall view of the planet Earth clearly shows concentrations of life in particular areas, such as the tropic and temperate regions in contrast to relatively barren deserts and portions of the polar regions. A more restricted view, considering the oceanic life from the shore zone to mid-ocean (Fig. 1) also reveals pronounced areal differences in quantity of plant and animal life. On a still smaller scale are the dense concentrations of aquatic life represented by schools of fish, coral reefs, shellfish beds, and similar groupings.

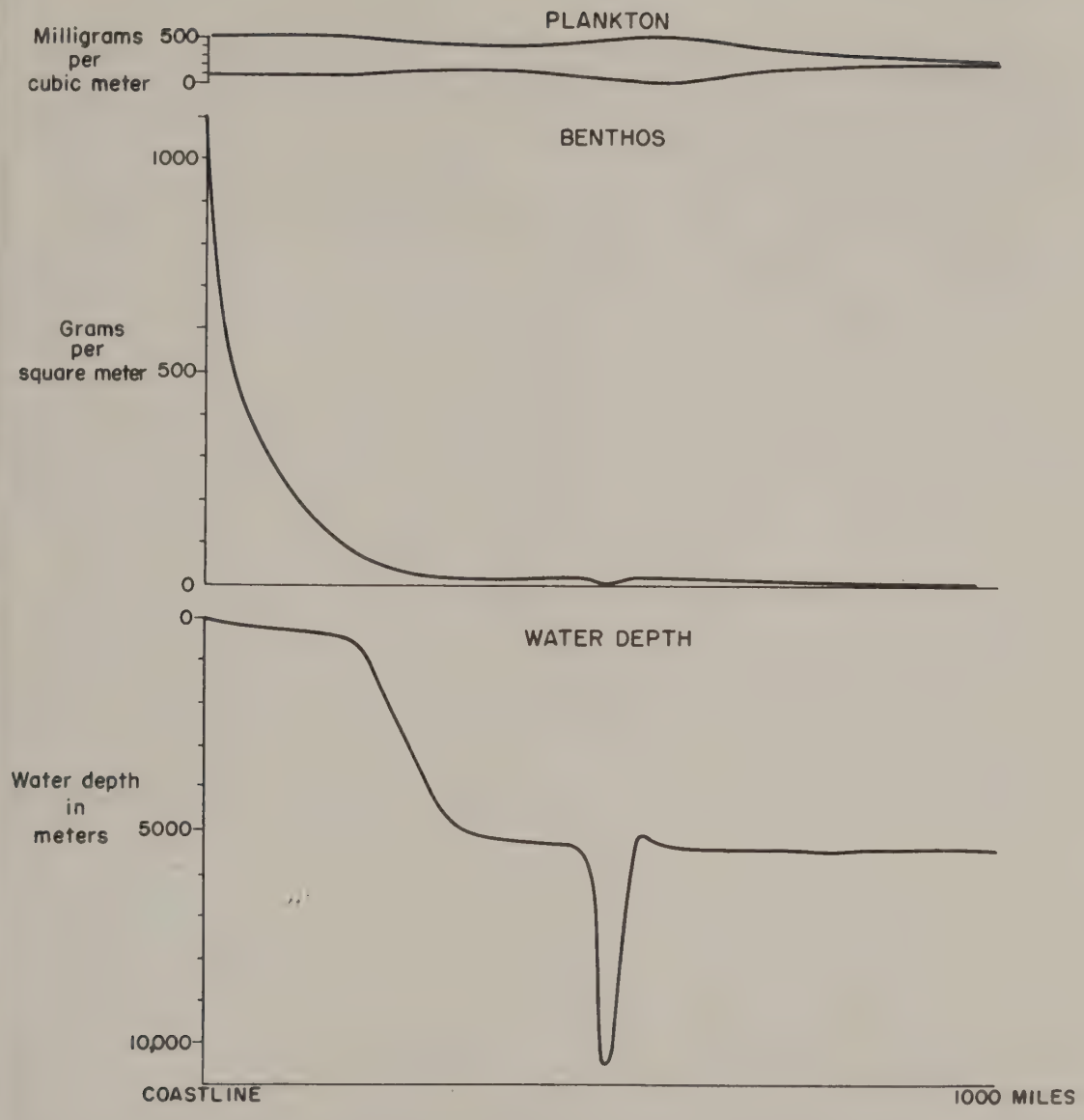

Fig. 1. Quantitative changes in the standing crop of plankton and benthos from shore to 1,000 miles offshore (modified after Zenkevich, 1956).

"Contagious distributions are the rule in nature. Sessile as well as motile animals settle or collect in favorable localities...." according to Allee *et al.*, (1949). Moreover, third in the list of aggregations cited by the same authors is "Collections about food". Clarke (1954) states ".....sources of food or shelter similarly serve as a focal point at which animals from the surrounding areas tend to congregate."

The aggregation of fish and other aquatic organisms about their food is particularly pertinent to the subject of this report. The following few examples have been selected from the literature to examplify the type of relationship considered here.

Plankton-feeding whales (humpback, *Megaptera*, blue, fin, and sei, *Balaenoptera*) concentrate in areas where planktonic organisms, chiefly euphausiids and copepods, upon which they feed, are most abundant. This relationship has been well documented (Hjort and Ruud, 1929; Hardy and Gunther, 1935). Reports of nekton feeding whales, dolphin, *Delphinus*, and the false killer whale, *Pseudorca*, also stress the association with schools of fish and cuttlefish, *Sepia*, (Legendre, 1922, Hinton, 1928).

Herring, *Clupea*, is a good example of pelagic species which aggregate in areas where their foods are present in abundance. Reports by Lucas (1936) and Hardy, *et al.*, (1936) deal with the correlation between the density of *Calanus*, the principal food of North Sea herring, and the quantity of herring caught by commercial fishermen. These reports clearly show that the herring catch was largest where *Calanus* was abundant and the catch was considerably lower where *Calanus* was sparse. Based on this relationship, a special plankton sampler called the plankton indicator was developed by Dr Hardy and his associates for use by commercial herring fishermen to assist them in locating suitable fishing grounds.

Fishing records show that tuna, such as albacore, *Thunnus*; bluefin, *Thunnus*; skipjack, *Katsuwonus*; yellowfin, *Neothunnus*, and related species, concentrate in areas of high biological productivity. Investigations by King and Ikehara (1956) and King and Hida (1957) revealed a general correspondence between zooplankton abundance and large catches of yellowfin tuna. Skipjack, according to Schaefer (1961), tend to be most abundant in highly productive areas where their forage is most plentiful. Yabe *et al.* (1963), in summarizing some of the literature pertaining to tunas and their environment, reported that several studies by other scientists defined the area of largest concentration of albacore in the North Pacific as being closely associated with the highly productive "transition zone", and that upwelling and divergence zones in the mid-Pacific equatorial waters produce very favorable conditions for increased productivity and consequently affect the abundance of yellowfin tuna. Laevastu and Rosa (1963) state "...the best tuna fishing areas coincide with more productive areas in the tropics and medium latitudes. A general relation between tuna abundance and abundance of macro-plankton and small nekton holds true in general". Howard (1963) concluded, "Observations on the nature and occurrence of commercial concentrations of tunas have shown they aggregate in particular localities. Beyond their direct response to surface temperature, and perhaps other factors not yet recognized, the important reference is their food supply".

The sea lamprey, *Petromyzon*, in Cayuga Lake, New York, exhibited marked differences in abundance from one section of the lake to another. The two sections of the lake containing the highest lamprey density were the same areas where lake trout, *Salvelinus*, were most abundant (Wigley, 1959).

F.M. Davis at Lowestoft, England, was one of the few biologists who have reported on the density dependent nature of marine groundfish and their food supply. In 1923 he stated, "...it seems reasonable to suppose the discovery of rich feeding grounds will throw light on the shoaling of food fish. In this connection it is interesting to note that the position of [a dense patch of *Spisula* and *Mactra*] was given to several skippers of Seine Boats working out of Lowestoft and Yarmouth and two of them found young haddock in large quantities — one of them after failing on other grounds — in June 1923. The fish were gorged with shell remains".

Evidence that fish concentrations, and their foods, occur in deep as well as in comparatively shallow water is apparent from the statement by Murray and Hjort (1912): "Even down to 500 fathoms the 'Michael Sars' found just as many fishes as on the bank, viz, about 300 fishes in one haul, and these were not small. At the same time the trawl was also crammed with other animals." Some of the "other animals" were presumably prey for the fish.

For many fish species, feeding aggregations are closely interrelated with feeding migrations. Thus, a brief consideration of migrations is appropriate before concluding this discussion.

Migrations of fishes stem from two major biological requirements, (1) food and (2) reproduction. We are concerned here only with the former. Nikolsky (1963) described the general sequence of events motivating a feeding migration as follows: "As they consume their food organisms, the fish reduce the concentration of food to a level at which energy expended in obtaining food cannot ensure the necessary rate of accumulation of the energy resources. When they have reduced the concentration of the food organisms below a certain level (which varies from species to species of both food and fish) the fish must move away and seek further concentrations of food organisms."

Feeding migrations may be active or passive, vertical or horizontal, and the periodicity of migration is most commonly diurnal or annual. Of special interest to the theme of this report is the

aggregation of juveniles and adults on the feeding grounds resulting from either active or passive migration or a combination of both. It has been well documented that a variety of different fishes (salmon, *Oncorhynchus*, *Salmo*; trout, *Salmo*; herring, *Clupea*; cyprinids, Cyprinidae; sturgeon, *Acipenser*; cod, *Gadus*; pilchard, *Sardinia*; porbeagle, *Lamna*; mackerel, Scombridae; swordfish, *Xiphias*; whitefish, *Coregonus*; bream, *Abramis*; tunny, *Thunnus*; and many others) undertake food-motivated migrations (Norman, 1947; Nikolsky, 1963). These migrations need not be reviewed for the purposes of this report, but two examples pertaining to marine groundfish are relevant to subsequent sections.

Smidts' (1951) studies of the Danish Waddensea fauna revealed a summer migration of 0-group plaice into the wadden at precisely the time the greatest quantities of microfauna, upon which plaice feed, were present. Zenkewich, *et al.*, (1928) report a study in the Barents Sea that illustrates another food-related groundfish migration. The authors state the "...distribution of production in the Barents Sea is evidently connected with the migration of the cod and haddock, and with the distribution of some other fishes of industrial importance. The cod and haddock, in moving eastward, keep for the most part along the edges of shallows, their final goal being the Petchora waters and those near the Kanis peninsula, where food is plentiful."

To briefly summarize, a general application of ecological principles together with specific examples, cited in the foregoing account, signifies that contagious distributions are not only common in nature, but more specifically, may be expected for many marine groundfish species. Furthermore, a concentration of food organisms undoubtedly provides a strong stimulus affecting groundfish aggregations, particularly when food shortages exist.

NEW ENGLAND GROUNDFISH

Bottom-dwelling fishes inhabiting New England offshore waters clearly exhibit a contagious distribution. Commercial landings data (Power, 1962; Ackerman, 1941; and others), although grouped according to rather large geographical areas, reveal sizable differences in quantity of fish caught on the various fishing grounds. This information gives a gross indication of groundfish aggregations. Another indication of groundfish aggregations is the fishing effort by the commercial fleet. Large differences in effort from one area to another are obvious (Schuck, 1952; Colton, 1955). Undoubtedly the prospect of larger catches on particular fishing grounds strongly influences the selection of areas to be fished. More detailed information concerning the distribution of New England groundfish is the work by Colton (1955), in which he describes the spring and summer distribution of haddock on Georges Bank. This species was found to have a pronounced contagious distribution. Some of the principal factors evaluated and found to be associated with haddock distribution were: geographical area, season of year, water depth, and age of haddock.

More recent information showing aggregations of New England groundfish was obtained from two sources: (1) commercial landings statistics, and (2) research vessel catch records.

Commercial landings statistics for United States medium and large trawlers in 1962 are one data source analyzed specifically for this report to calculate groundfish density distribution. Only those trips in which trawler captains were interviewed to determine the geographic area fished, fishing effort (days fished), and related data were used in this analysis. Although information from this source represents only a small portion of the total fishing effort, it provides a reasonably good index of localities fished, and the catch rate in various sections of the New England area.

Groundfish inventories made by the US Bureau of Commercial Fisheries research vessels are the second source of groundfish distribution data. Autumn inventories by *Albatross III* and *Delaware* during the years 1955 to 1961, were analysed. These vessels used a standard No. 36 otter trawl (24-m groundrope and 18-m headrope) with a fine-mesh liner. Values from this source are based on the number of fish caught per 30-min haul. A total of 588 otter trawl hauls were made in the study area.

Dominant fish species comprising the catch in both the commercial landings data and research vessel catch were: haddock, *Melanogrammus*; cod, *Gadus*; silver hake, *Merluccius*; pollock, *Pollachius*; redfish, *Sebastes*; butterfish, *Poronotus*; yellowtail, *Limanda*; winter flounder, *Pseudopleuronectes*; and American dab, *Hippoglossoides*. The spiny dogfish, *Squalus*, was abundant in research vessel catches, but was not present in commercial landings.

The haddock, one of the most abundant New England groundfishes, has been selected to illustrate the density-distribution of a single species. The autumn distribution of haddock in New

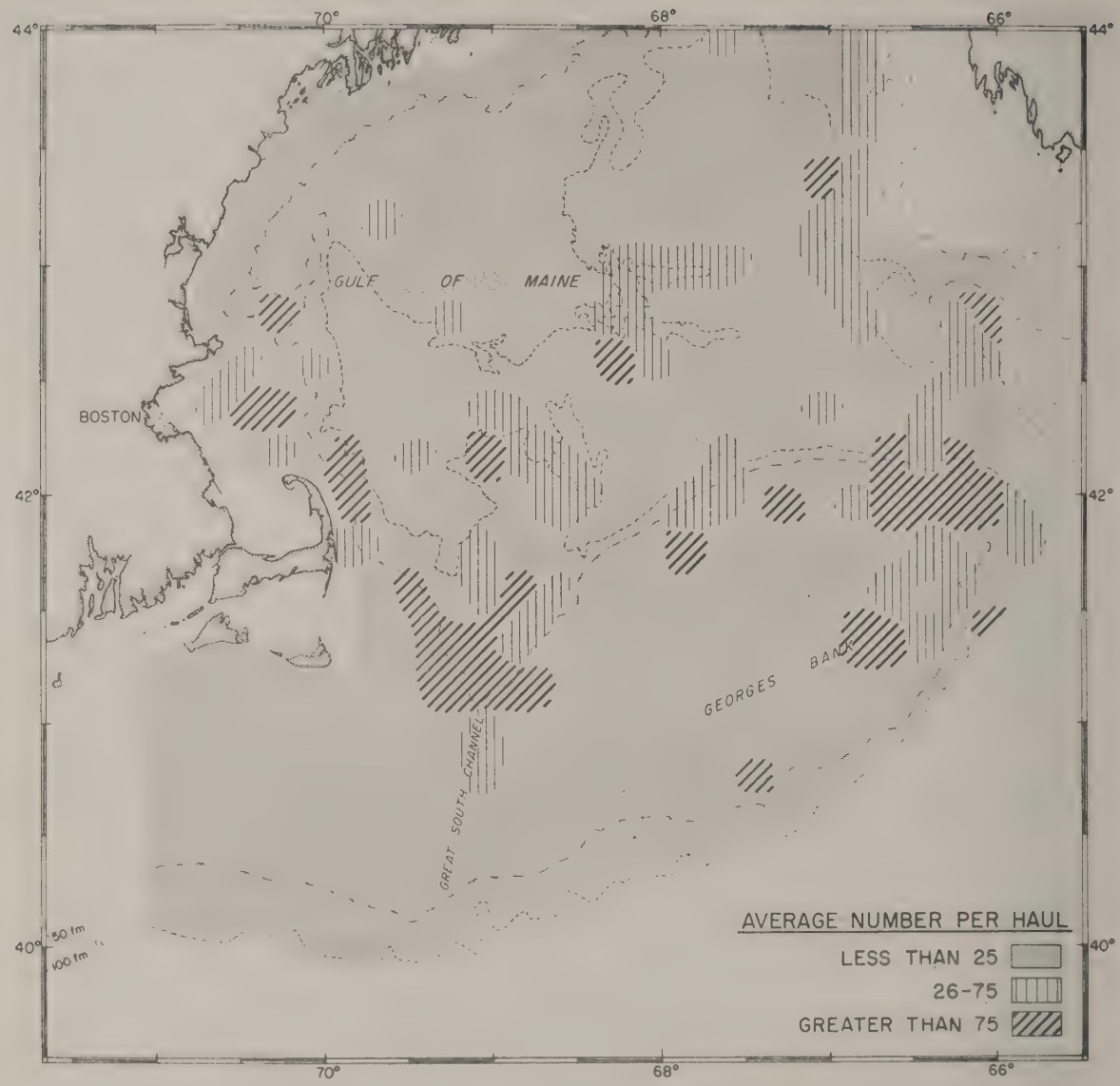

Fig. 2. Autumn density-distribution of haddock based on inventories conducted by research vessels *Albatross III* and *Delaware* from 1955 through 1961. Values are mean numbers of haddock caught per 30-min haul in a No. 36 otter trawl.

England offshore waters is shown in Fig. 2. This distribution chart is based on the mean number of haddock per haul for each 12-min section of latitude and longitude resulting from research vessel trawl catches from 1955 through 1961. It is apparent that haddock are abundant in some areas and sparse in others. Both this information and data presented by Schuck (1952) and Colton (1955) disclose that haddock concentrations occur chiefly in the northern and eastern sections of Georges Bank and in the vicinity of Great South Channel.

[illegible] all species combined — are aggregated in a similar manner, and in some of the same localities as haddock, is shown by the following data. Illustrated in Fig. 3 is

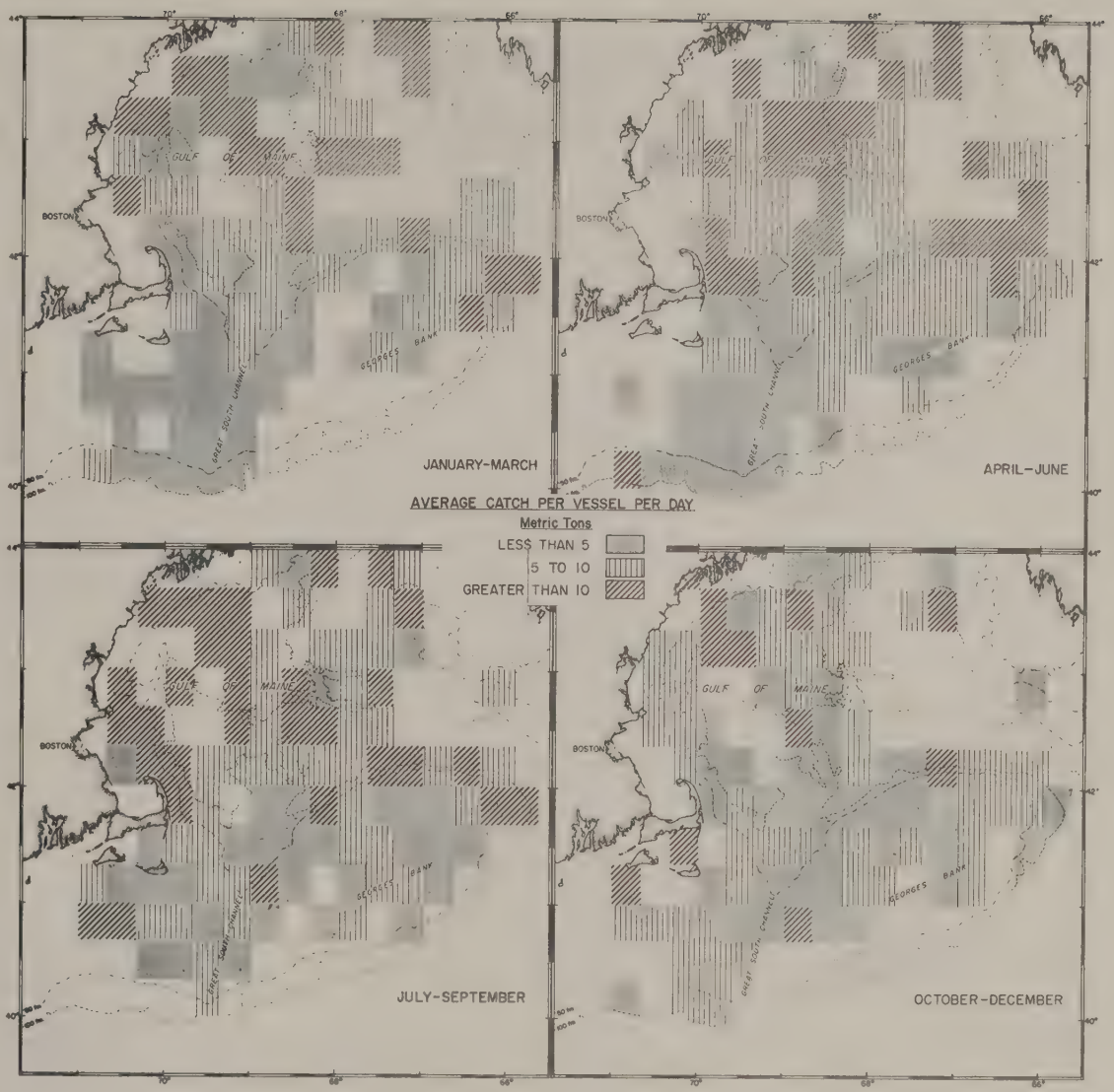

Fig. 3. Seasonal density-distribution of New England groundfish based on commercial landings statistics for 1962. Values are catch per vessel per day in metric tons.

the catch (metric tons) per vessel per day by the commercial fishing fleet for each season of the year. This chart is based on mean value per 20-min section of latitude and longitude. Groundfish concentrations occurred in all seasons, but were least pronounced during the fourth quarter, October-December. Wide fluctuations in the catch rate occurred in coastal areas and south of Cape Cod and the islands of Martha's Vineyard and Nantucket. This is due mainly to large catches of migrant species in April-June and July-September. Relatively high catch rates were maintained throughout the year in large areas in and near Great South Channel (particularly in the northern part), northern and eastern Georges Bank, and several sections in the Gulf of Maine. Catch rates remained relatively low at all seasons in southwestern and east-central Gulf of Maine and southwestern Georges Bank.

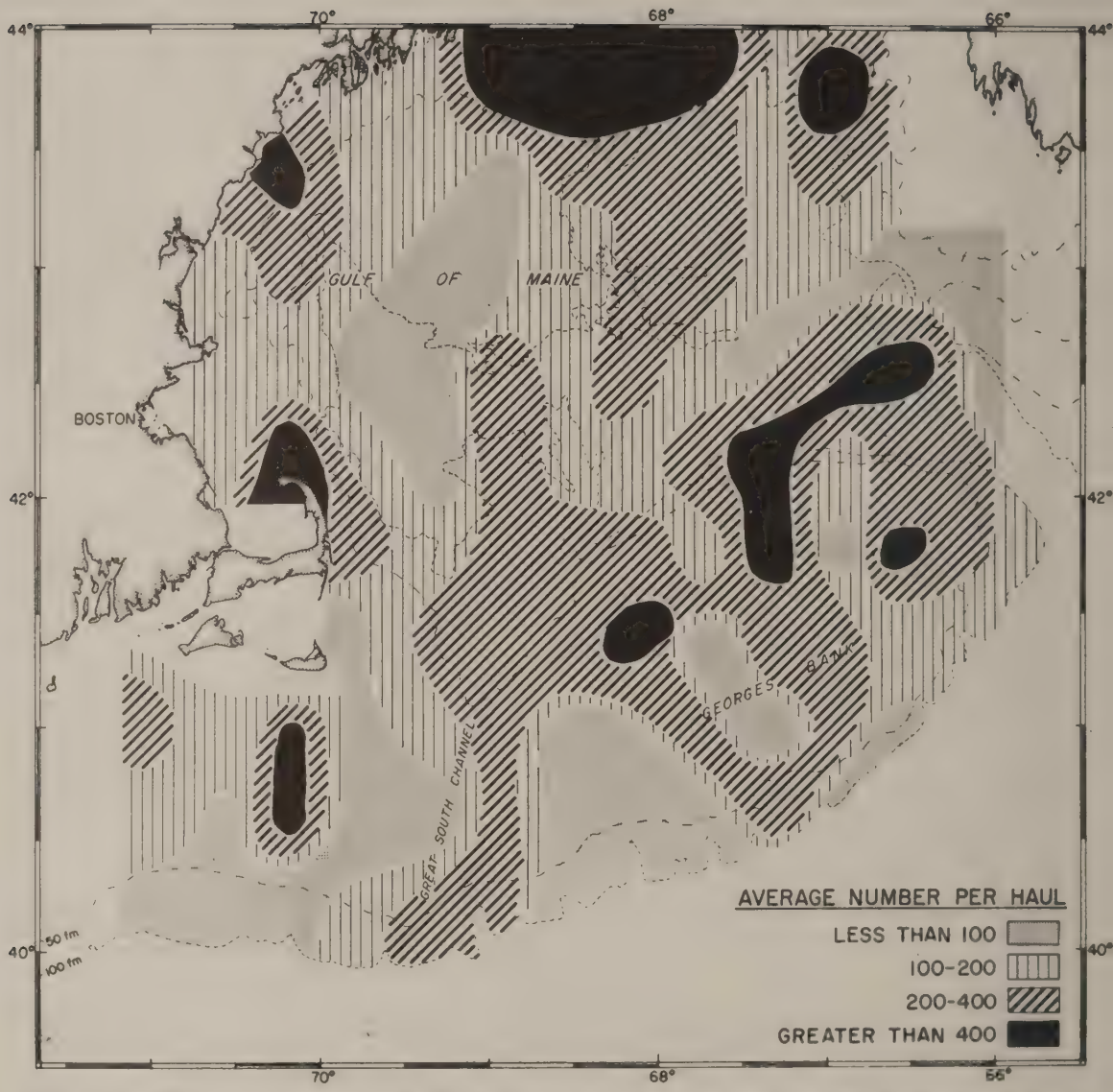

Fig. 4. Autumn density-distribution of New England groundfish based on inventories conducted by research vessels *Albatross III* and *Delaware* from 1955 through 1961. Values are mean number caught per 30-min haul in a No. 36 otter trawl.

Research vessel trawl catches reveal a groundfish density-distribution pattern similar to that described above. The mean number of groundfish per trawl haul in fall census cruises of 1955 throug 1961 is shown in Fig. 4. Basis for this chart are mean values for each 24-min section of latitude and longitude. Large catches were prevalent over much of Georges Bank, especially on the northern part; Great South Channel; and the western, northern, and central portions of the Gulf of Maine, plus somewhat localized areas along the coast and south of Cape Cod and the islands of Martha's Vineyard and Nantucket. Low catches were common on southwest Georges Bank, west-central and east-central Gulf of Maine, and portions of the area south of Cape Cod and adjacent islands.

In both the commercial and research vessel catches the occurrence of semi-pelagic groundfish species - which accounts for a significant proportion of the Gulf of Maine catch - should be given general consideration until this subject is investigated and treated quantitatively.

The quantitative comparison between the distribution of groundfish and their food supply is the subject of this section. Principal source of nourishment for New England groundfish appears to be holobenthic and merobenthic invertebrate organisms (Bigelow and Schroeder, 1953; Wigley, 1956). Small fishes, of course, are an important food for many large groundfish but a substantial number of these small prey fishes also depend heavily on benthic organisms for food.

The one available quantitative measure of groundfish food supplies on the New England Continental Shelf is based on samples of macrobenthic invertebrates. This information was rather difficult and time consuming to obtain due to the enormous area involved, strong tidal currents, deep water, and coarse bottom sediments. However, some preliminary estimates of the benthic biomass were obtained during the summer months from 1957 to 1962. A total of 426 quantitative samples collected with a Smith-McIntyre grab sampler have been analysed. The analysis procedure consisted of washing each sample through a 1-mm mesh screen and weighing (wet weight) the retained fauna. Wet weights were converted to dry weights by using conversion factors derived from representative specimens. The results are plotted in Fig. 5. In order to present a more accurate measure of the food supply, polychaete tubes, mollusk shells, and calcareous matter in other organisms are omitted.

Distinct differences in macrobenthos density from one area to another are apparent in Fig. 5. Particularly noticeable is the quantitatively rich benthic fauna south of Cape Cod and the islands of Martha's Vineyard and Nantucket. The Gulf of Maine biomass is rather low, and that in the vicinity of Georges Bank is intermediate. High benthos density is common in the Great South Channel area, northern edge of Georges Bank, and north-central Gulf of Maine, in addition to its prevalence south of the islands. Intermediate density is especially widespread in the Gulf of Maine area. Low density occurs over extensive areas in the Gulf of Maine and Georges Bank.

The density distribution of benthic organisms (Fig. 5) compared geographically with groundfish density (Figs. 3 and 4) shows a general similarity between the two. For example, Great South Channel, northern periphery of Georges Bank, portions of the Gulf of Maine, and a large part of the area south of Cape Cod and the islands of Martha's Vineyard and Nantucket have high densities of both fish and invertebrates. Conversely, low densities of both categories occur in west-central Gulf of Maine, and southwestern and southeastern Georges Bank. A few areas, such as northern Gulf of Maine and some areas south of Cape Cod and the islands, show either an inverse correlation or no correlation.

A more specific comparison of the relationship between density of groundfish and food supply, is that between haddock (Fig. 2) and benthic invertebrates (Fig. 5). A comparison of these two components discloses a reasonably good correlation, except in the southwestern portion of the study area. It should be noted that haddock is a boreal species and would not be expected to occur in large numbers in the temperate waters in the southwestern portion of this region.

Although the long-range objective of obtaining detailed information necessary for density comparisons between each groundfish species and its food supply has not yet been attained, further evaluation of existing data is expected to provide useful results. Two principal aspects now under consideration are: (1) the pelagic feeding excursions of some groundfish species, and (2) the ranking or classifying of benthic organisms according to their energy value and utilization as foods by groundfish.

SUMMARY AND DISCUSSION

Aggregations of natural animal populations, both large and small, commonly result from biological as well as physical-chemical influences. The density or degree of concentration in these populations is sometimes related in a predictable manner to environmental factors. Reports in the literature indicate that a variety of animal groups, such as insects, birds, mammals, and pelagic fishes (1) congregate where foods are plentiful, and (2) that food shortages can limit population size and alter its structure (size, age, sex ratio).

In the past, little research has been devoted to quantitative aspects of groundfish food supplies. Also, little is known about species composition, population structure, and density distribution of groundfish stocks as related to food supplies. Scarcity of quantitative studies of

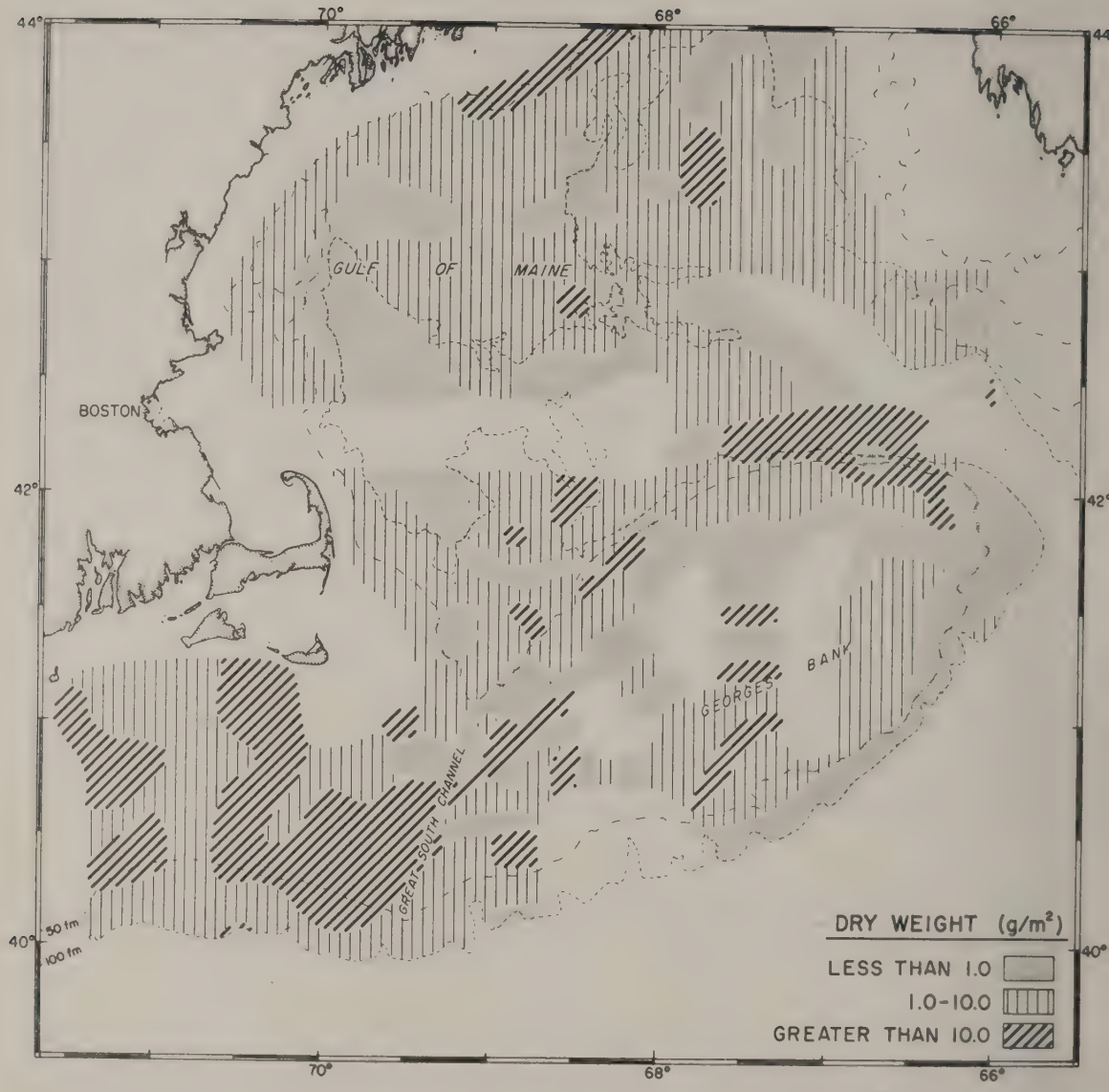

Fig. 5. Biomass of the macrobenthic invertebrate fauna collected with a Smith-McIntyre grab sampler. Values are dry weight (grams) per square meter.

groundfish density and food organisms over sufficiently large areas have impeded studies on this subject. A little information is now available bearing on this aspect of New England offshore groundfish. Research vessel census data and commercial fishery catch records indicate that New England groundfish tend to aggregate in specific, geographic localities. Also, quantitative measures of benthic invertebrates reveal pronounced aggregations of these organisms. Of special interest is the fact that geographically the correlation in density between groundfish and benthic invertebrates is generally good. This correlation warrants further investigation, since it is anticipated that inventories of groundfish and their food, conducted simultaneously or nearly so, would provide an index to the well being of existing populations and yield clues to future changes in abundance, size and age composition, fecundity, and related biological characteristics.

I thank Mr Raymond L. Fritz and personnel in the biostatistical unit at the Bureau of Commercial Fisheries Biological Laboratory, Woods Hole, for providing groundfish inventory data and assistance in processing catch statistics.

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Made in United States of America
Reprinted from Transactions of the American Fisheries Society
Vol. 94, No. 3, July 1965
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ABSTRACT

Stomach contents of 941 juvenile and adult haddock collected at monthly intervals at the Highlands Ground off Cape Cod, Massachusetts, from February 1958 to January 1959 were analyzed. Approximately equal numbers of both sexes were represented. Weight of stomach contents from individual fish ranged from 0 to 48.2 grams; average weight was 2.2 grams. There were no indications of important differences between males and females in species of animals preyed upon or quantities of food ingested. Mean stomach content weight increased as haddock size increased from 25 to 70 centimeters in length, but specimens longer than 70 centimeters contained unexpectedly small quantities of food. There was a marked seasonal variation in the quantity of food in the stomachs. A low feeding rate prevailed during late summer, fall, winter, and early spring, followed by heavy feeding in June. Water temperature appeared to be relatively unimportant in affecting the feeding rate. A wide variety of small benthic organisms were represented in the diet. The more important species are listed. The principal food groups, in order of decreasing importance were: Crustacea, Annelida, Pisces, Echinodermata, and Mollusca. Some differences in diet were associated with haddock size. Small organisms (amphipods, cumaceans, brittlestars) were more common in small haddock. Relatively large foods (decapod crustaceans, fish) were prevalent in large haddock only. Distinct seasonal changes in diet composition were detected. Crustacea and Pisces varied substantially and quite sharply, as opposed to Echinodermata which exhibited smaller, more gradual changes. The proportion of Annelida in the diet was quite uniform throughout the year.

INTRODUCTION

Differences in the kind and quantity of foods eaten by haddock (*Melanogrammus aeglefinus* L.) at various seasons of the year have not been studied in sufficient detail to give a clear understanding of this subject. Even major factors such as whether or not adult haddock fast during the spawning season, are not without contradiction (Homans and Vladykov, 1954; Wigley, 1956). The purpose of this report is to present information concerning the quantities of food and kinds of organisms preyed upon by haddock at one locality during a 12-month period. Quantitative and qualitative differences by season, sex, and size are discussed.

MATERIALS AND METHODS

A selected sample of haddock was collected each month (except July) during the period from February 1958 to January 1959 aboard a commercial otter trawler. The selection of specimens was designed to provide maximum size range and approximately equal numbers of both sexes. These specimens were taken from a comparatively small area known as the Highlands Ground, located 42°15′ N lat, 70°00′ W long, 15 miles northeast of Provincetown, Massachusetts. Water depths here range from 50 to 60 fathoms (approximately 100 to 120 meters) and the bottom sediments are predominantly sands and gravels. Bottom water temperatures were obtained from bathythermograph casts each time biological collections were made.

Total number of haddock utilized in this study was 941, of which 458 were males and 483 were females. They ranged in length (fork length) from 25.0 to 76.2 cm. Males and females both averaged 44.8 cm in length. A catch-record summary is listed in Table 1. A formalin solution was injected into the stomachs immediately after the fish were caught to halt digestion and preserve the contents. A short time later, length, sex, and gonad development of each haddock were recorded, and the stomachs were removed and individually labeled to correspond to these data.

Contents of the stomachs from each fish were weighed individually. The contents from all stomachs in each month's collection (except February) were then combined to form a composite sample. After the faunal components of the sample were sorted to species or species groups, the number of individuals and damp weight (after blotting) were recorded for each species. The analysis of the February collection, which was the first collection, was considerably more detailed than the

TABLE 1.—*Haddock catch record*

Date collected	Number of haddock			Length[1] of haddock (cm)		
	Males	Females	Total	Minimum	Maximum	Average
12 February 1958	53	53	106	29.6	68.2	47.6
9 March 1958	44	50	94	28.7	73.5	44.9
11 April 1958	42	48	90	26.1	76.2	47.0
12 May 1958	47	42	89	28.7	73.7	49.2
8 June 1958	29	37	66	34.3	71.6	49.3
9 August 1958	30	22	52	25.0	72.0	42.7
14 September 1958	50	55	105	25.2	58.9	41.2
14 October 1958	46	52	98	27.6	69.9	43.7
13 November 1958	40	50	90	26.4	69.5	45.2
11 December 1958	25	27	52	26.0	67.0	37.5
15 January 1959	52	47	99	26.2	75.3	42.2

[1] Fork length, i.e., from snout to caudal fin notch.

TABLE 2.—*Mean haddock length and stomach-content weight for males, females, and both sexes combined, in each 10-cm length class*

Length class (cm)	Male		Female		Both sexes	
	Mean length (cm)	Mean stomach content (g)	Mean length (cm)	Mean stomach content (g)	Mean length (cm)	Mean stomach content (g)
20.0–29.9	28.43	0.82	27.55	0.39	27.95	0.59
30.0–39.9	35.79	1.20	35.35	1.07	35.55	1.13
40.0–49.9	44.99	1.60	45.16	2.33	45.08	1.95
50.0–59.9	53.62	2.19	54.12	2.83	53.87	2.51
60.0–69.9	63.28	5.11	63.87	5.66	63.61	5.42
70.0–79.9	70.80	0.98	73.26	3.04	72.36	2.29

others in order to determine if there were important dietary differences between males and females. Stomach contents from each specimen were individually sorted, counted, and weighed. Both the number of individuals and the weight of each component group were used in the analyses. Because of large differences in the size of food organisms, weight is a more meaningful measure than number, and it is the measure most extensively used herein.

QUANTITY OF STOMACH CONTENTS

Similarity Between Sexes

At this point it is desirable to assess the differences or similarities in stomach content quantity between male and female haddock. If no important differences exist, the data for both sexes may justifiably be grouped together in subsequent discussions in order to utilize the maximum amount of data. Major differences between sexes would, of course, require separate consideration for each.

Homans and Vladykov (1954) reported there was no significant difference in the feeding rate between sexes of haddock on the offshore Nova Scotian banks. Also, personal observations by Wigley of several hundred haddock from Georges Bank did not disclose any obvious differences between sexes in stomach-content volume. In the present study mean differences in weight of food in stomachs between males and females within 10-cm size classes were computed for every month. A t test was employed, using a pooled (all months) estimate of standard deviation. All values of t were found to be less than 1.34 (degrees of freedom were from 2 to 5 inclusive), thus none were significant at the 0.05 probability level. These results indicated there were no statistically significant differences between sexes in stomach-content weight. Therefore, in the following discussions the data from both sexes have been combined.

Relation to Size

Large haddock with their proportionately larger stomachs were expected to contain a greater quantity of food than smaller haddock. This is exactly the relationship that was found for specimens ranging in length from 25 to 70 cm, but the very large specimens, those over 70 cm, contained unexpectedly small amounts of food (Table 2). Haddock from 25 cm up to 55 cm in length exhibited a rather even increase in stomach content weight of about 0.07 g for each 1-cm length increment. Between about 50 and 70 cm in length the rate increased sharply to 0.29 g/cm. Specimens in the 60.0 to 69.9 cm length class contained the largest quantity of food, average weight was 5.4 g each, whereas those in the 70.0 to 79.9 cm length class contained only about half as much (2.3 g). This unexpectedly small quantity may have resulted from the small sample of haddock represented in this length class. There were no indications of regurgitation, and the possibility exists that the pronounced decrease in stomach contents in these large specimens (> 70 cm) may possibly be due to debilitation.

Seasonal Variations

There was a pronounced seasonal change in the feeding activity of Highlands Ground haddock. This change was indicated by a seasonal shift in the mean stomach-content

TABLE 3.—*Mean stomach content weights and bottom-water temperature. Values in parentheses are the number of specimens upon which the mean values are based*

Haddock size class (cm)	Mean stomach content weight (grams)										
	Feb.	Mar.	Apr.	May	June	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.
20.0–29.9	0.1	1.0	1.1	4.9	—	0.7	0.3	0	0.6	0.5	0.3
	(1)	(3)	(1)	(1)	—	(3)	(5)	(1)	(4)	(12)	(13)
30.0–39.9	0.5	0.8	3.1	1.3	3.1	1.6	0.7	0.4	1.0	1.0	0.6
	(16)	(36)	(23)	(19)	(13)	(20)	(44)	(33)	(18)	(23)	(25)
40.0–49.9	1.8	1.3	2.8	4.0	4.6	2.7	1.8	0.9	1.0	1.8	1.0
	(52)	(25)	(33)	(27)	(24)	(19)	(42)	(45)	(44)	(8)	(43)
50.0–59.9	2.8	1.4	1.7	2.2	7.1	3.7	2.1	1.2	1.0	4.4	1.3
	(30)	(20)	(24)	(28)	(19)	(8)	(14)	(16)	(18)	(8)	(14)
60.0–69.9	6.0	3.8	2.5	1.3	18.7	1.3	—	5.3	2.2	4.6	3.5
	(7)	(8)	(7)	(11)	(8)	(1)	—	(3)	(6)	(1)	(3)
70.0–79.9	—	0	4.0	1.3	2.5	1.8	—	—	—	—	6.5
	—	(2)	(2)	(3)	(2)	(1)	—	—	—	—	(1)
All sizes combined											
Mean of size classes	2.2	1.7	2.5	2.5	7.2	2.0	1.2	1.6	1.2	2.5	2.2
Mean of individuals	2.2	1.3	2.5	2.4	6.7	2.2	1.3	0.9	1.1	1.6	1.0
Bottom-water temperature (C)	4.2	3.6	3.3	3.3	3.3	4.2	6.1	7.0	8.1	7.2	5.0

weight. The main feature of this change was a striking increase in feeding which took place during June. Data pertaining to seasonal feeding is given in Table 3. The mean stomach-content weight for all fish jumped from 2.5 g in May to about 7 g in June. This increase was most pronounced for specimens 60.0 to 69.9 cm in length. Their stomach-content weight increased from an average of 1.3 g in May to 18.7 g in June. Haddock 50.0 to 59.9 cm in length also exhibited a distinct increase of feeding activity in June, but specimens less than 50 cm showed only a moderate increase. This differential feeding pattern between size groups appears to be related to sexual maturity and spawning activity.

Reports by Homans and Needler (1944), Bigelow and Schroeder (1953), and Homans and Vladykov (1954) state that haddock refrain from eating during the spawning season, at least in some localities. The opposite situation was reported by Needler (1930). He found spawning haddock of both sexes with well-filled stomachs. Studies conducted by Ritchie (1937), McKenzie (1940), and Wigley (1956) revealed an intermediate situation; a decline in the quantity of food eaten during the spawning season, but substantial evidence of active feeding.

The spawning season for Highlands Ground haddock in 1958 was March to May inclusive, with the height of spawning taking place in April. Considering specimens of all sizes, the feeding rate was not diminished during this period. The data listed in Table 3 demonstrate a relatively high quantity of food in the stomachs throughout the spawning period; considerably more than during the fall and winter seasons. The smaller fish, those between 20.0 and 49.9 cm in length, actually feed as much or more during this period than at any other time of year except June. The 60.0 to 69.9 cm length class was the only one (of six) which showed a steadily decreasing feeding rate from March through April, whereas the other five length classes exhibited an increasing trend during this period.

Nearly all specimens less than 40 cm in length were immature, thus any direct relation between haddock spawning and food intake would be expected to pertain only to those specimens more than 40 cm in length, the adult fish. There are three length classes of adults with enough specimens to indicate feeding trends. They are: (1) 40.0 to 49.9 cm, (2) 50.0 to 59.9 cm, and (3) 60.0 to 69.9 cm. As indicated in Table 3, specimens in length-class 1 did not diminish their feeding rate during the spawning season, and increased their feeding only slightly in the post-spawning period (June). Fish in length-class 2 exhibited a moderately low feeding rate during the spawning period, followed by a rather sharp post-spawning increase in feeding. Haddock in length-class 3 distinctly decreased their feeding during the spawning season, and fed heavily during June.

From the foregoing, it may be concluded that immature and small mature Highlands Ground haddock feed heavily during the

spawning season. The smallest groups feeding more heavily at this season than at any other time of year. Large, mature fish tend to slacken their feeding rate during the spawning season, and then gorge themselves shortly afterward.

Relation to Temperature

A number of cold-water fishes, including haddock, are known to eat more and grow faster at higher temperatures, within their range of tolerance, than at lower temperatures (Brice, 1897; Fulton, 1904; Dawes, 1930; Davis, 1953; and others). McKenzie (1932) reported that the best catches of haddock taken by means of baited hooks in the Bay of Fundy region were made when bottom water temperatures were between 7 and 10 C. None were caught when temperatures were below 2 C. In waters near Halifax, Nova Scotia, Vladykov (1934) found that the highest catches with baited hooks were made at temperatures from 4 to 7 C, whereas between 11 and 13 C only small catches were obtained. On the Nova Scotian offshore banks Homans and Vladykov (1954) observed that a reduction in the proportion of haddock containing food was coincident with abnormally high (8.5 to 11 C) water temperatures.

Our data disclosed no significant relationship between stomach-content quantity and water temperature. The somewhat larger quantities of food in the stomachs during low temperature periods than when temperatures were high (Table 3) suggest an inverse relationship between feeding rate and water temperature. However, a statistical evaluation of the relation between temperature and stomach-content weight of haddock 30.0 to 39.9 cm in length, an immature group of limited size range, gave a correlation coefficient of -0.52 ($df = 9$). This value is not statistically significant. We thus conclude that the observed range in bottom-water temperature did not strongly influence the feeding rate of Highlands Ground haddock.

Since haddock can survive at temperatures as high as 14 to 20 C (Vladykov, 1934), and optimum catches on baited hooks were made at 4 to 10 C (McKenzie, 1932; Vladykov, 1934), the temperatures at the Highlands Ground during the fall and winter, 5 to 8 C, were not deleteriously high. The generally small quantity of food in the stomachs during the warmwater period (September through January) appears to be due to factors other than a temperature related increase in metabolic activity. Perhaps the supply of available foods, interspecies competition for food, defensive action, or the result of spawning activities may outweigh and/or conceal the expected temperature-related changes in feeding rate.

Average Quantity

The arithmetic mean stomach-content weight for all fish examined in this study is 2.0 g. The unweighted average of monthly means, which eliminates bias due to unequal numbers sampled at different months, is 2.2 g. Considering that these haddock averaged 44.8 cm in length, this appears to be a much smaller amount of food than would intuitively be expected in fish of this size. However, there is evidence that supports the validity of this small quantity of food. Haddock from Scottish waters, although smaller than Highlands Ground specimens, had an average stomach-content volume of roughly 1.7 cc (Ritchie, 1937). Also, the average stomach-content volume of Georges Bank haddock in 1953 to 1954, which were very similar in size to Highlands Ground specimens, was 2.2 cc (Wigley, 1956). It thus appears that small quantities of food in haddock stomachs are typical for this species.

DIET COMPOSITION

Annual Summary

Highlands Ground haddock preyed upon a wide variety of organisms. Benthic animals heavily predominated and the ratio of invertebrates to fish was 4 : 1 in terms of weight. Nearly all the food organisms were sedentary or slow-moving forms. A condensed summary of stomach-content components for all specimens examined is listed in Table 4. In this compilation the monthly means for each food group are given equal weight.

Crustaceans were the primary food. Annelid worms and fishes formed a secondary, but substantial, share of the diet. Echinoderms, mollusks, and miscellaneous groups (see Table 5 for components of the miscel-

TABLE 4.—*Average stomach-content composition of Highlands Ground haddock, all samples combined*

Item	Number of individuals per 100 haddock	Weight (grams)	
		Per 100 haddock	Percentage
Crustacea	1,524	63.9	28.9
Annelida	788	33.1	14.9
Pisces	9	30.1	13.6
Echinodermata	219	13.7	6.2
Mollusca	155	8.7	3.9
Miscellaneous	36	1.1	0.5
Mucus	—	38.9	17.6
Unidentified	—	32.0	14.4

laneous category) comprised a rather minor portion of the diet.

Haddock are noted for the diversity of food organisms they prey upon. Verrill (1873) stated, "A complete list of the animals devoured by the haddock would doubtless include nearly all species belonging to this [southern New England] fauna." In the Highlands Ground haddock we encountered more than 100 different organisms which we were able to identifiy to species, plus quite a few others which were classified only to genus, family, or other taxa. Although this is a rather wide variety of foods from one locality, it is in keeping with the known habits of haddock.

Haddock typically select small organisms for food, and some of these small and moderately small organisms were the principal food sources for haddock on the Highlands Ground. Among the amphipods, *Leptocheirus pinguis*, *Unicola irrorata*, and *U. inermis* were particularly important. Juvenile specimens of the following crustacean decapods provided a significant share of the food: *Cancer borealis*, *C. irroratus*, *Dichelopandalus leptocerus*, and *Hyas coarctatus*. The following cumaceans occurred quite regularly in the diet, but only in small quantities: *Diastylis quadrispinosa*, *Eudorella hispida*, and *Petalosarsia declivis*. Two mollusks that occurred regularly in the diet, and in large quantities, were *Cerastoderma pinnulatum* and *Nucula tenuis*. Mol-

TABLE 5.—*Stomach contents of haddock expressed as mean number of specimens per 100 haddock*[1]

Food group	Feb.	Mar.	Apr.	May	June	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Total
Crustacea	1,553	1,042	999	2,526	8,192	976	191	166	159	757	199	16,760
Amphipoda	1,431	945	918	2,442	8,108	717	136	123	143	708	146	15,817
Copepoda	—	—	—	—	—	10	—	—	—	—	—	10
Cumacea	92	67	68	63	15	229	49	31	13	8	43	678
Decapoda	23	21	13	18	30	10	6	4	3	14	10	152
Isopoda	6	—	—	3	39	10	—	8	—	27	—	93
Mysidacea	—	9	—	—	—	—	—	—	—	—	—	9
Euphausiacea	1	—	<1	—	—	—	—	—	—	—	—	1
Mollusca	121	192	270	99	197	303	179	69	100	72	199	1,711
Amphineura	—	—	—	—	—	—	11	4	—	8	5	28
Cephalopoda	—	—	—	—	—	—	3	—	—	—	—	3
Gastropoda	6	9	22	18	24	10	9	—	10	8	29	145
Pelecypoda	114	93	248	81	173	293	156	65	90	48	165	1,526
Scaphopoda	1	—	<1	—	—	—	—	—	—	8	—	9
Echinodermata	237	305	342	148	77	406	108	88	165	196	334	2,406
Asteroidea	9	—	—	3	—	—	—	—	—	—	—	12
Echinoidea	18	—	27	24	62	125	9	4	7	148	34	458
Holothurioidea	1	—	4	—	—	—	—	—	—	—	5	10
Ophiuroidea	209	305	311	121	15	281	99	84	158	48	295	1,926
Annelida	575	260	522	173	4,724	770	262	195	270	540	383	8,674
Nereidiformia	128	17	9	24	—	208	74	103	90	169	121	943
Sabelliformia	2	—	—	—	—	—	—	4	—	—	—	6
Scoleciformia	24	—	—	—	4,332	208	20	4	30	129	126	4,873
Spioniformia	96	—	—	—	—	—	—	—	—	—	—	96
Terebelliformia	19	—	—	—	—	104	49	38	33	67	63	373
Unidentified	306	243	513	149	392	250	119	46	117	175	73	2,383
Miscellaneous	113	8	13	3	16	31	29	31	30	—	29	303
Brachiopoda	—	—	—	—	—	—	3	—	—	—	—	3
Bryozoa	<1	—	—	—	—	—	—	—	—	—	—	<1
Coelenterata	1	—	—	—	8	—	—	—	3	—	—	12
Nematoda	107	—	—	3	8	—	6	4	7	—	10	145
Nemertea	—	—	—	—	—	21	17	8	13	—	14	73
Pycnogonida	1	4	—	—	—	—	—	8	—	—	—	13
Sipunculida	4	4	13	—	—	10	3	11	7	—	5	57
Sand and stone	+	—	+	—	—	—	+	—	—	—	—	+
Pisces	16	4	27	18	24	—	3	—	3	—	—	95
Mucus	+	+	+	+	+	+	+	+	+	+	+	+
Unidentified	<1	<1	<1	<1	<1	—	<1	4	—	—	—	4
Total number	2,615	1,721	2,173	2,967	13,230	2,486	772	553	727	1,565	1,144	29,953
Number of haddock	106	94	90	89	66	52	105	98	90	52	99	941

[1] Plus sign refers to the presence of items where numbers were not obtainable.

TABLE 6.—*Stomach contents of haddock expressed as mean weight (grams) per 100 haddock*

Food group	Feb.	Mar.	Apr.	May	June	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Total
Crustacea	65.00	64.30	59.54	61.40	375.60	8.66	3.60	5.71	1.63	45.92	12.00	703.36
Amphipoda	23.00	29.30	16.20	56.70	372.40	6.50	1.10	1.10	1.60	11.90	1.20	521.00
Copepoda	—	—	—	—	—	< 0.01	—	—	—	—	—	< 0.01
Cumacea	1.20	0.20	0.04	0.20	< 0.01	0.06	0.20	0.10	0.03	0.02	0.10	2.15
Decapoda	40.20	34.70	7.30	4.10	3.20	1.90	2.30	4.50	< 0.01	32.30	10.70	141.20
Isopoda	0.50	—	—	0.40	< 0.01	0.20	—	0.01	—	1.70	—	2.81
Mysidacea	—	0.10	—	—	—	—	—	—	—	—	—	0.10
Euphausiacea	0.10	—	36.00	—	—	—	—	—	—	—	—	36.10
Mollusca	11.90	3.10	22.40	2.00	6.40	5.80	35.70	1.44	2.30	1.08	4.04	96.16
Amphineura	—	—	—	—	—	—	0.10	0.04	—	0.08	0.04	0.26
Cephalopoda	—	—	—	—	—	—	32.60	—	—	—	0.60	33.20
Gastropoda	1.10	—	0.30	0.30	4.70	< 0.01	0.50	—	0.30	0.20	3.40	10.80
Pelecypoda	10.80	2.60	4.10	1.70	1.70	5.80	2.50	1.40	2.00	0.80	—	33.40
Scaphopoda	< 0.01	0.50	18.00	—	—	—	—	—	—	—	—	18.50
Echinodermata	26.30	11.70	24.20	6.30	16.60	16.70	3.80	2.32	4.60	23.60	14.60	150.72
Asteroidea	1.20	—	—	0.20	—	—	—	—	—	—	—	1.40
Echinoidea	10.10	—	7.70	3.00	15.80	12.30	1.10	0.02	0.60	21.50	4.00	76.12
Holothurioidea	0.10	—	1.40	—	—	—	—	—	—	—	0.20	1.70
Ophiuroidea	14.90	11.70	15.10	3.10	0.80	4.40	2.70	2.30	4.00	2.10	10.40	71.50
Annelida	28.30	21.60	93.30	28.40	66.90	31.80	20.40	14.44	17.80	27.60	13.20	363.74
Nereidiformia	16.10	9.30	40.60	11.70	—	25.80	17.10	12.50	12.00	23.30	6.20	174.60
Sabelliformia	0.10	—	—	—	—	—	—	0.04	—	—	—	0.14
Scolecciformia	1.60	—	—	—	29.20	3.10	1.40	0.40	3.30	2.70	5.60	47.30
Spioniformia	1.60	—	—	—	—	—	—	—	—	—	—	1.60
Terebelliformia	0.60	—	—	—	—	0.80	0.50	0.50	0.20	0.20	0.40	3.20
Unidentified	8.30	12.30	52.70	16.70	37.70	2.10	1.40	1.00	2.30	1.40	1.00	136.90
Miscellaneous	4.30	0.10	< 0.01	0.03	< 0.01	0.80	2.93	0.70	2.62	—	0.30	11.78
Brachiopoda	—	—	—	—	—	—	2.30	—	—	—	—	2.30
Bryozoa	< 0.01	—	—	—	—	—	—	—	—	—	—	< 0.01
Coelenterata	1.40	—	—	—	< 0.01	—	—	—	0.20	—	—	1.60
Nematoda	< 0.01	—	—	0.03	< 0.01	—	< 0.01	< 0.01	0.02	—	0.10	0.15
Nemertea	—	—	—	—	—	0.60	0.60	0.60	2.10	—	0.10	4.00
Pycnogonida	< 0.01	< 0.01	—	—	—	—	—	0.02	—	—	—	0.02
Sipunculida	0.40	0.10	< 0.01	—	—	0.20	0.03	0.08	0.30	—	0.10	1.21
Sand and stone	2.50	—	—	—	—	—	< 0.01	—	—	—	—	2.50
Pisces	23.40	0.60	125.00	118.30	30.20	—	29.80	—	4.00	—	—	331.30
Mucus	21.60	20.93	—	21.73	31.53	107.60	54.00	43.27	48.73	42.93	35.13	427.47
Unidentified	31.60	14.27	90.00	21.47	29.07	53.80	27.00	21.67	24.37	21.47	17.57	352.27
Total weight	212.40	136.60	414.44	259.63	556.30	225.16	177.23	89.55	106.05	162.60	96.84	2,436.80
Number of haddock	106	94	90	89	66	52	105	98	90	52	99	941

lusks of secondary importance were *Margarites, Astarte*, and *Nuculana*. *Ophiura sarsi* and *Echinarachnius parma* were the only echinoderms which provided a significant part of the haddock's diet. The principal annelids in the diet were *Aphrodita hastata* and *Nephtys* (mainly *incisa*); of secondary importance were *Glycera* sp., *Lumbrineris fragilis, Goniada maculata*, and *Sternaspis scutata*. Although fish composed a major portion of the diet, they are relatively large items for haddock to prey on. There was little consistency in the species taken, but they were all juvenile specimens. The identifiable species encountered were: *Hippoglossoides platessoides, Merluccius bilinearis, Macrozoarces americanus*, and *Etrumeus sadina*.

Similarity Between Sexes

There was no biological evidence known to us that indicated male haddock should differ from female haddock in their food perferences. However, since the data were available it was of interest to compare diets. Due to pronounced differences in dietary habits between large and small haddock (see below, Relation to Size), only specimens between 40 and 60 cm in length were considered in this comparison between sexes. Forty-two males and 40 females from the February collection were studied. The males ranged in length from 41.2 to 58.8 cm, and averaged 48.3 cm; females ranged from 40.6 to 59.7 cm, and averaged 49.4 cm.

In Table 8 the percentage number and weight of all major stomach-content groups are listed separately for males and females. There were virtually no differences between sexes in the proportion of numbers of the various dietary components. In regard to the weight of various food groups, the females contained a somewhat higher proportion of crustaceans and a smaller amount of fish in their diet than males. All other groups were present in approximately equal quantities.

Both sexes also preyed upon essentially the same species of food organisms. Species

TABLE 7.—*Diet composition of four size groups of haddock collected in February 1958*[1]

	Percentage number of specimens				Percentage weight			
	Length class (cm)				Length class (cm)			
Food group	30.0–39.9	40.0–49.9	50.0–59.9	60.0–69.9	30.0–39.9	40.0–49.9	50.0–59.9	60.0–69.9
Crustacea	79.9	47.2	42.3	94.3	18.4	21.9	36.6	42.7
Amphipoda	67.0	43.5	36.8	94.0	10.2	7.6	2.6	35.7
Copepoda	—	0.1	—	—	—	< 0.1	—	—
Cumacea	12.4	2.3	3.4	—	6.9	0.6	0.3	—
Decapoda	0.3	0.8	1.7	0.2	1.2	13.3	33.5	4.7
Isopoda	—	0.4	0.3	0.2	—	0.3	0.2	2.3
Euphausiacea	—	0.1	—	—	—	0.1	—	—
Mollusca	0.8	5.5	7.5	2.0	2.6	7.2	5.2	3.3
Gastropoda	—	0.4	2.9	0.2	—	0.9	< 0.1	0.7
Pelecypoda	0.8	5.1	4.6	1.8	2.6	6.2	5.2	2.6
Echinodermata	7.0	11.0	11.1	2.2	16.5	18.2	9.5	3.0
Asteroidea	—	0.1	0.1	—	—	1.0	0.3	—
Echinoidea	—	1.0	1.0	—	—	9.0	2.6	—
Holothurioidea	—	—	0.1	—	—	—	0.1	—
Ophiuroidea	7.0	9.9	9.9	2.2	16.5	8.2	6.5	3.0
Annelida	3.8	29.8	35.7	0.7	9.0	17.9	16.3	< 0.1
Nereidiformia	0.6	7.4	7.3	—	5.1	10.6	9.4	—
Sabelliformia	—	—	0.3	—	—	—	0.1	—
Scoleciformia	—	0.9	1.7	—	—	0.3	1.7	—
Spioniformia	1.6	6.2	3.7	—	1.2	1.2	0.6	—
Terebelliformia	—	0.4	2.2	—	—	0.2	0.5	—
Unidentified	1.6	14.8	20.5	0.7	2.6	5.6	4.0	< 0.1
Miscellaneous	8.6	5.4	3.0	0.7	< 0.1	3.3	0.1	3.5
Coelenterata	—	—	—	0.2	—	—	—	3.5
Nematoda	8.6	4.6	2.9	0.6	< 0.1	< 0.1	< 0.1	< 0.1
Pycnogonida	—	0.1	—	—	—	< 0.1	—	—
Sipunculida	—	0.3	0.1	—	—	0.4	< 0.1	—
Sand and stone	—	0.4	—	—	—	2.8	< 0.1	< 0.1
Pisces	—	1.1	0.4	0.2	< 0.1	1.6	13.8	28.2
Mucus	+	+	+	+	45.8	17.4	11.8	10.1
Unidentified	+	+	+	+	7.7	12.5	6.8	9.2
Number of stomachs examined	16	52	30	7	16	52	30	7

[1] Plus sign refers to the presence of items where numbers were not obtainable.

which formed the bulk of the diet for both males and females are, for the most part, those listed above. Observed differences in species in the diet were the occurrence of *Protomedeia fasciata, Hyas coarctatus, Pandalus borealis,* and *Sternaspis scutata* in females but not in males. Species preyed on by males but not by females were: *Axius serratus, Colus pygmaeus, Crenella glandula,* and *Strongylocentrotus drobachiensis.*

The above information indicates that during February there were no important or consistent sex-related differences in diet composition between medium-sized male and female haddock.

Relation to Size

Different food habits related to the size of haddock have been demonstrated in other studies (Ritchie, 1937; Homans and Needler, 1944). It is our purpose here to briefly report similar results for Highlands Ground haddock based on the February collections. In this sample of 106 haddock, ranging in length from 29.6 cm to 68.2 cm, there were marked differences in diet composition between small-, medium-, and large-sized specimens. In Table 7 are listed the percentage weights and percentage numbers of the various taxonomic groups in each of the following length classes: 30.0 to 39.9 cm, 40.0 to 49.9 cm, 50.0 to 59.9 cm, and 60.0 to 69.9 cm. The one specimen in the 20.0 to 29.9 cm length class has been omitted. Also, due to relatively few haddock (7) in the 60.0 to 69.9 cm length class, the values in this category are probably not representative, and values for this size category were given little consideration in interpreting the data in this table.

The diet of large haddock in this sample was composed of a much higher proportion of crustaceans and fish, and a slightly higher proportion of annelids and mollusks, than was the diet of small haddock. On the other hand, the relative amount of echinoderms in the diet was less in large haddock than in small ones. The average weight of fish in the diet increased from less than 1% in the 30.0 to 39.9 cm length class to 14% in the 50.0 to 59.9

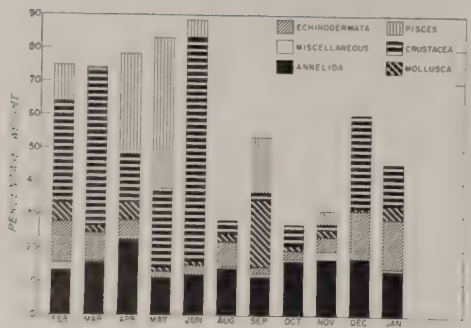

FIGURE 1.—Percentage weight of major food groups by months.

cm length class. Crustacea increased from 18% in the 30.0 to 39.9 cm length class to 37% in the 50.0 to 59.9 cm length class.

The three principal crustacean components were: amphipods, cumaceans, and decapods. Of these three groups, the first two are small-sized animals and they decreased in quantity with increased haddock size, whereas the last (decapods) are relatively large organisms and they increased in quantity as haddock size increased. In nearly all cases these changes in percentage weight, as associated with haddock length, were also accompanied by similar changes in percentage number of specimens.

Seasonal Variations

Little is known about seasonal changes in the composition of the haddock's diet. The reason for this is that most previous studies have not been based on samples taken throughout the year at the same locality. Unless the geographic variation is taken into consideration, the enormous differences in diet from one locality to another may mask seasonal dietary variations.

In this study, because the samples were taken during 11 months of the year at one locality, quantitative seasonal variations in the haddock's diet are evident. Stomach analysis data for each month are listed separately by numbers of organisms (Table 5) and weights of organisms (Table 6). In these tables the values for each major taxonomic group and subgroup are given in terms of 100 haddock. This adjustment is made to counteract the varied number of haddock stomachs in the monthly samples. Thus the resulting data are directly comparable. To illustrate seasonal trends in diet composition, monthly mean weights for each major food group have been converted to percentages and plotted in the form of a histogram in Figure 1.

TABLE 8.—*Diet composition of male and female haddock 40 to 60 cm in length taken in February 1958*

Food group	Percentage by number		Percentage by weight	
	Male	Female	Male	Female
Crustacea	46	44	24	33
Mollusca	7	6	6	6
Echinodermata	11	11	16	13
Annelida	32	32	16	18
Miscellaneous	3	6	<1	3
Pisces	1	1	13	2
Mucus	—	—	16	14
Unidentified	—	—	9	11
Total	100	100	100	100

Fish and crustaceans exhibited the greatest seasonal variations. Fish were taken in largest quantities during April and May. The maximum per cent (45.6) was recorded for May. During the other months fish were absent, or present in small quantities. Crustacea were preyed upon quite heavily during the winter, spring, and early summer. Two months when the percentage weights of crustacea were highest were March (47.1%) and June (67.5%). Exceedingly heavy predation on amphipods took place in June when the haddock were eating heavily after spawning. Very small quantities were present in the diet during the period August through November.

There was no evident seasonal cycle in consumption of Mollusca or Miscellaneous groups.

Echinoderms formed an important share (12 to 15%) of the diet in winter and early spring. Following this period their relative importance declined and remained low (2 to 7%) during the summer. In late fall the proportion increased, and reached its maximum in January.

The Annelida were outstanding in their relatively uniform occurrence in the diet throughout the year. Minimum and maximum monthly percentage weights were 10.9 in May and 22.5 in April.

Nematodes occurred in moderately small numbers in this collection of haddock, but their occurrence is of some interest from the parasitological viewpoint. All nematodes found in these fish are believed to be parasitic

forms, and as such they have little significance as a food resource, yet it is interesting to note their steady decline in number in the larger haddock.

ACKNOWLEDGMENTS

We sincerely thank John R. Clarke, Albert C. Jensen, and John P. McDermott, U. S. Fish and Wildlife Service, for providing the stomach collections and associated data upon which this report is based.

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The Interrelationship Between Phytoplankton and Zooplankton in Inshore Waters Near Beaufort, North Carolina

RICHARD B. WILLIAMS, *U. S. Bur. Comm. Fisheries, Beaufort, N. C.*

A yearlong study was made of plankton in Core Sound and adjoining embayments, an area of 400 km² with a mean depth of only 1.2 m. Average values for phytoplankton production and zooplankton standing crop were obtained at 5-week intervals for the entire area. Net production of phytoplankton ranged from 41 to 310 mg C/m²/day and had a pronounced seasonal cycle paralleling that of water temperature. The zooplankton (exclusive of ctenophores and large medusae) was chiefly copepods and fluctuated irregularly between 0.022 and 0.258 ml/m³. The organic carbon needed to support this zooplankton was estimated to comprise from less than 0.1% to 1% of the daily net production. These data suggest that in the area studied, the supply of phytoplankton never limited the production of zooplankton, and that the grazing of zooplankton never controlled the abundance of phytoplankton.

Abstract reprinted from the *ASB Bulletin*, Vol. 12, No. 2, p. 55, April 1965.

A THALASSOMYCES SP. (ELLOBIOPSIDAE) INFESTING ACANTHOMYSIS PSEUDOMACROPIS AND NEOMYSIS KADIAKENSIS (MYSIDACEA) IN SOUTHEASTERN ALASKA

Bruce L. Wing

A species of the parasitic ellobiopsid genus Thalassomyces has been found on two species of mysids, Acanthomysis pseudomacropis and Neomysis kadiakensis from Auke Bay, Southeastern Alaska. A description of the external portion of this ellobiopsid is given and its relationship to Th. boschmai and Th. nouveli is discussed.

Reprinted from:
Ocean science and ocean engineering, 1965. Vol. 1, Trans. Joint Conf. Exhib., Mar. Technol. Soc. Amer. Soc. Limnol. Oceanogr. [Abstract.]

Note: pseudomacropsis is misspelled in title.

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Reprinted from Limnology and Oceanography
Vol. 10, No. 1, January 1965
pp. 156–157

The Optical Comparator as a Tool in Plankton Research

INTRODUCTION

The sorting, counting, and measuring of plankton is a tedious and error-prone procedure, and the difficulties are compounded when the operation must be performed under a microscope. One of the projects of the Biological Laboratory of the Bureau of Commercial Fisheries at La Jolla, California, is the analysis of samples consisting mainly of organisms less than 1 mm in length. The optical comparator represents an improvement over the low-powered (9–15×) dissecting microscope usually used in this work and has proved a valuable aid in dealing with certain of the problems involved.

DESCRIPTION

Comparators[1] were designed for industrial use to provide extreme precision in the inspection of small parts. The model now in use at the La Jolla laboratory is equipped with both substage and surface illuminators, a mobile stage, a trinocular objective turret, and a 300-mm-diameter ground-glass screen that is divided into quadrants by crosslines (Fig. 1).

The stage is rotatable through an arc of more than 300°. Wheels control gross movement, providing scanning fields of 11.5 cm laterally and 6.5 cm from front to back. Extremely fine measurements can be made with two micrometer drums reading to 0.001 inch (0.0025 cm).

The three magnifications that we have chosen are 20×, 50×, and 120×. The diameter of the screen is filled by a 15-mm object at 20×, a 6-mm object at 50×, and a 2.5-mm object at 120×. Clearance between stage and lens is 40 mm at 20×, 17 mm at 50×, 9 mm at 120×. For the higher magnifications, it is necessary to darken the room. Partial darkness is required for 50× and helpful for 20×.

[1] Various models are known as projection comparators, optical projectors, shadowgraphs, and microprojectors.

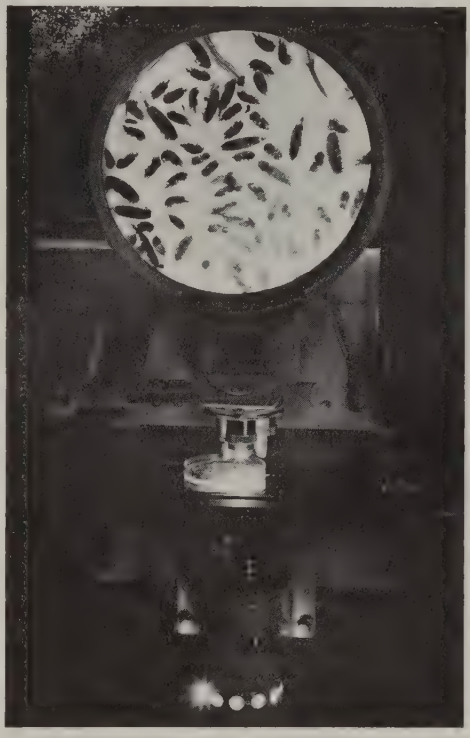

Fig. 1. A plankton sample projected onto the screen of the optical comparator at 20×. Length of the large copepod at mid-center right is 2.47 mm.

Photographic attachments for regular or Polaroid film are quickly and easily interchangeable with the screen.

The reversed image that this model projects is the only disadvantage we have encountered to date.

DISCUSSION

Error in plankton biometrics is reduced by the comparator in the following ways:

1) Measurement. By placing a flexible transparent ruler over the enlarged image, it is possible to measure specimens regardless of orientation in the sorting dish. Greater accuracy results from the direct reading of the larger calibrations of the

superimposed ruler and, with no need for alignment, measuring proceeds very rapidly. For example, the cephalothorax lengths of 180 copepods were recorded in 16 min.

Standardization of measurement is difficult at the low magnifications usually used, since demarcations of body divisions or fine details of extremities that affect total length (for example, caudal fin rays of a chaetognath) are often indistinct. The enlarged image provided by the comparator defines such features more clearly, making consistent treatment possible.

The length of curved specimens can at best be approximated under a microscope, but even coiled chaetognaths can be measured on the comparator's screen by bending the ruler, or by superimposing a calibrated plastic cord on the image.

2) Enumeration. Counting error arising from jarring of the sorting dish is minimized by the mechanically moved stage. There is no need to touch the container, nor, to assure accuracy of count, is it necessary to remove specimens as they are tallied. Instead, each specimen can be recorded as its image crosses the vertical line on the screen.

3) Physical strain is alleviated by the natural posture possible when using the comparator, and the larger sweep of movement permitted the eye reduces eyestrain.

Additional features

The easily mounted attachments simplify photography or, as in Fig. 1, a photograph may be taken of the screen itself, and direct tracings of the enlarged image can be made. Further, the comparator's screen can be observed by several persons simultaneously.

With living organisms, the movement of minute particules into the gut of a siphonophore and ciliary action in molluscan veligers have been clearly observed. It is apparent that the comparator has great potential for investigation of the living organism.

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Reprinted from PACIFIC SCIENCE, *vol. XIX, no. 4, October 1965*

New Pacific Records of Juvenile Albacore *Thunnus alalunga* (Bonnaterre) from Stomach Contents

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BECAUSE THE ALBACORE, *Thunnus alalunga* (Bonnaterre), is commercially one of the more valuable species of tuna, a great deal of effort has been expended in investigating its biology. Although much has been learned in recent years about the albacore, its age and growth, movements and migrations (Otsu, 1960; Clemens, 1961; Otsu and Uchida, 1963), many facets of the biology of this species still need to be studied. As part of the Albacore Ecology Program, staff members of the Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii, have been studying the early life history of albacore in order to fill the gaps in our knowledge.

There is a paucity of information on the juvenile[2] and larval stages of albacore due in part to two factors. One is the limited success of efforts to collect the young, and the other is the difficulty of identifying them, since adult morphological characters are often inadequate for identifying the young stages. Although there has been some success in collecting juvenile tunas with various types of midwater trawls (Matsumoto, 1961), most of the juvenile tunas recorded in the literature have come either from stomachs of predators or from dipnetting at nightlight stations. Yabe, Ueyanagi, Kikawa, and Watanabe (1958) reported on five juvenile albacore less than 30 cm discovered in stomachs of predators caught in the western North and South Pacific Ocean. So far as I know, theirs is the only documented record of juvenile albacore in the Pacific Ocean, and it has positively demonstrated albacore spawning in these areas.

In June 1960, a program was initiated at the Biological Laboratory, Honolulu, to sample stomachs of large pelagic fishes for juvenile albacore. This paper presents the results of sampling through November 1962. Twelve juveniles were found in stomachs of predators caught in the central North and South Pacific, thereby extending known or demonstrating new spawning grounds for albacore. Although the number of specimens is small, I consider it important to report them promptly since juvenile albacore are not very often collected and the information may be of value to other investigators studying the biology of the albacore.

SOURCE OF MATERIALS

Two sources of stomach samples that were readily available to the author were the large fishes landed by the Hawaiian commercial longline fishery and by exploratory fishing cruises of the Bureau of Commercial Fisheries' research vessel "Charles H. Gilbert."

The Hawaiian longline fishery is usually conducted within 20 miles of the main islands, with most of the boats in the fleet operating out of Honolulu, while smaller numbers fish out of Hilo and Kona on the island of Hawaii, and from Port Allen on the island of Kauai (Otsu, 1954). The catch of this fishery consists of a variety of large pelagic fishes, including striped marlin (*Makaira audax*), blue marlin (*Makaira ampla*), black marlin (*Istiompax marlina*), broadbill swordfish (*Xiphias gladius*), and shortnose spearfish (*Tetrapturus angustirostris*), among the spearfishes. Among the tunas, bigeye (*Thunnus obesus*), yellowfin (*Thunnus albacares*), and small numbers of albacore and skipjack (*Euthynnus pelamis*) are taken.

Stomachs were sampled at the auction markets of the United Fishing Agency, Ltd., and the Hawaiian Fishing Co., Ltd., in Honolulu. Since it has been shown that juvenile tunas occur more frequently in stomachs of spearfishes

[1] Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii. Manuscript received October 1, 1963.

[2] Unless otherwise noted, the term "juvenile" as used herein includes albacore up to 30 cm long.

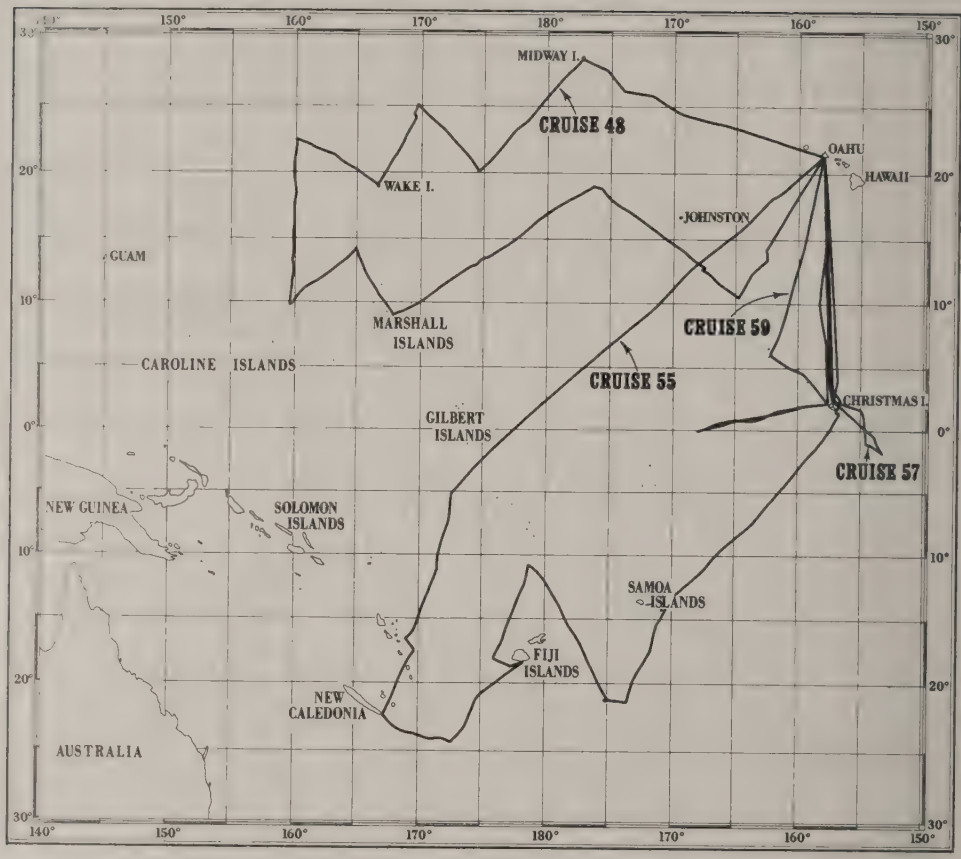

FIG. 1. Tracks of the "Charles H. Gilbert," cruises 48, 55, 57, and 59 (June 1960 to November 1962).

than of adult tunas (Yabe et al., 1958), and because it was not possible to sample all the fishes landed at the markets, emphasis was placed on sampling the spearfishes.

Other stomachs sampled were from fishes caught by longlining on four cruises of the "Charles H. Gilbert" during the period covered by this study and from fishes caught during the 1962 Hawaiian International Billfish Tournament held at Kona, Hawaii, from July 31 through August 4, 1962. The cruise tracks of the "Charles H. Gilbert" are shown in Figure 1.

IDENTIFICATION OF JUVENILE ALBACORE

As would be expected of specimens found in stomachs, our juvenile albacore specimens were in various stages of digestion. Specimens that retained most of their flesh were easily recognized as scombrids by the body contours and shape of the head (Fig. 2). Aside from the general shape, few of the external features of the specimens had escaped digestion sufficiently to be of any use in species identification. However, this was not a serious handicap, since the hard parts of the fish were relied upon for identification. In two of the specimens practically all of the flesh had been digested away and all that remained were the bony parts, but even these fish could be identified as albacore.

Yabe et al. (1958) discovered a striking vertebral character that is distinctive for albacore and used it in identifying juvenile albacore as

small as 12.4 cm in standard length. This character is the laterally flattened shape of the haemal spine of the first caudal vertebra (first elongate haemal spine) which is unique to albacore. It is interesting to note that although several investigators have studied the anatomy and morphology of albacore in great detail, the significance of this character was not recognized by them. Recently, Matsumoto (1963) investigated this structure in detail and showed conclusively that among the tunas it is only found in albacore.

The 12 juvenile albacore reported on here were identified on the basis of this character (Fig. 3). The flat haemal spine was readily observable in all of the specimens, the smallest of which measured an estimated 61 mm in standard length. The width of the spine was from about 1.3 to 2.3 times the width of the haemal spine following it. Furthermore, the juveniles possessed other albacore characters. As in adults, the juveniles had 7–9 + 1 + 19–21 = 27–30 gill rakers and 39 vertebrae (18 precaudals and 21 caudals).

DESCRIPTION OF JUVENILE ALBACORE

Although the specimens were partially damaged by digestion, counts and measurements were made on the juveniles whenever they could be made accurately (Table 1).

The shape of the juveniles is more or less fusiform. Each jaw has a single row of small teeth. Villiform teeth are present on the palatines and vomer. The snout is short and somewhat pointed; the mouth is moderate. The vertebrae number 18 + 21 = 39, including the urostyle. The first closed haemal arch is on the 10th vertebra. In two specimens the bones producing the arch on the 10th vertebra are in contact but not fused; in three specimens the arch is damaged. The angle made by the first closed haemal arch and the vertebral axis is

FIG. 2. Juvenile albacore 184 mm in standard length found in the stomach of a blue marlin caught off Kona, Hawaii, August 1, 1962. (The last few vertebrae became detached from the rest of the fish subsequent to measurement and are not shown in the photograph.)

approximately 75–90°. The first ventrally projecting parapophysis is on the 7th–9th vertebrae.

The posterior margin of the basioccipital, when viewed laterally, makes an angle of approximately 90° or more with the axis of the vertebral column in specimens smaller than 19 cm, and an acute angle in specimens about 25 cm and larger in standard length.

The intestine has the two folds characteristic of Thunnidae (Godsil and Byers, 1944).

Only one specimen had its first dorsal fin membranes intact; the fin membranes are covered with black pigmentation.

DISCUSSION

Although no attempt was made to study all the differences in the morphology of adult and juvenile albacore, a few of the more obvious ones were noted in some detail. As indicated earlier, the flattened haemal spine on the first caudal vertebra becomes definitive early in the life of albacore, since a juvenile 61 mm in standard length already possessed this character. A meristic character that also develops early is the gill raker count, for all of the juveniles already possessed the full adult complement. However, several morphological features of adult albacore were still in their early formative stages in the juveniles. These were the orientation of the parapophyses on the vertebrae preceding the ninth vertebra, the angle the first haemal arch makes with the axis of the vertebral column, the orientation of the bones constituting the first haemal arch, and the shape of the posterior margin of the basioccipital.

According to Godsil and Byers (1944) the parapophyses preceding the first haemal arch extend laterally in adults. In juveniles the tips of the parapophyses on the vertebrae as far anterior as the seventh may project ventrally. Presumably, with growth the anterior parapophyses tend to straighten out and extend later-

FIG. 3. Portion of axial skeleton of juvenile albacore showing unique, flattened haemal spine on first caudal vertebra.

TABLE 1
COUNTS AND MEASUREMENTS MADE ON JUVENILE ALBACORE
(Measurements in millimeters)

CHARACTER	SPECIMEN NUMBER						
	3	4	6	7	8	11	12
Standard length	—	—	88	74	184	—	—
Head length	—	—	—	19	48	—	—
Postorbital length of head	—	—	—	8	22	—	—
Iris diameter	—	—	—	6	—	—	—
Interorbital width	—	—	6	6	14	—	—
Snout length	—	—	6	5	—	—	—
Maxillary length	—	—	10	8	21	—	—
Snout to first dorsal origin	—	—	—	21	—	—	—
Snout to pelvic base	—	—	—	—	59	—	—
Longest pectoral ray	—	—	—	—	12	—	—
Gill rakers (number)							
Upper arch	7	7	7	9	8	8	7
Angle	1	1	1	1	1	1	1
Lower arch	20	20	19	19	21	20	20
Total	28	28	27	29	30	29	28
First dorsal fin	—	—	—	13	14	—	—

ally, starting with the anteriormost and ending with the parapophysis on the eighth vertebra. Actually, the tip of the parapophysis on the ninth vertebra projects ventrally and does not completely straighten out even in adults.

The first haemal arch in adult albacore makes an angle of 45° or less with the axis of the vertebral column, and the bones of the arch are flattened dorso-ventrally (Godsil and Byers, 1944). In juveniles the first haemal arch makes an angle of approximately 75–90°, with the greater angles generally occurring in the smaller specimens. The bones of the arch are flattened laterally. Evidently, as the albacore grows, the angle that the arch makes with the axis of the vertebral column becomes more acute. At the same time the posterior margins of the arch move forward and inward so that in adults the bones are compressed dorso-ventrally (Fig. 4).

Godsil and Byers (1944:84) state that the posterior margin of the parasphenoid and basioccipital, when viewed laterally, makes a prominent acute angle in adult albacore. However, a few paragraphs later (p. 85) they state that this margin may make an angle varying from slightly acute to somewhat obtuse. For our purpose, this character is perhaps best described as the angle the posterior margin of the basioccipital makes with the axis of the vertebral column. When the cranium is viewed from the side, this angle is acute in adult albacore. In small juveniles this angle is obtuse, but with growth it changes to approximately 90° and finally to an acute angle (Fig. 5). A juvenile measuring 257 mm already possessed a skull similar to an adult. However, in a 184 mm specimen, the angle was still 90°. Therefore, it appears that this character becomes definitive in albacore at a standard length somewhere between 184 and 257 mm.

Yabe et al. (1958) found that juvenile tunas occurred more frequently in stomachs of spearfishes than of tunas. However, they also found that this varied according to area. Juvenile tunas occurred in stomachs of spearfishes and yellowfin tuna caught in low-latitude waters, but not in bigeye tuna. North of 30° N, however, juvenile tunas were also found in bigeye stomachs. Yabe and his colleagues suggested that this was due to a difference in vertical distribution of tunas and spearfishes, which in turn was related to the hydrography of the different areas. Although our sampling program was not designed to make such a comparison, most of our juvenile albacore were found in stomachs of spearfishes (Table 2). Six were found in the stomachs of five blue marlin, three in the stomachs of three striped marlin, two in the stomach of

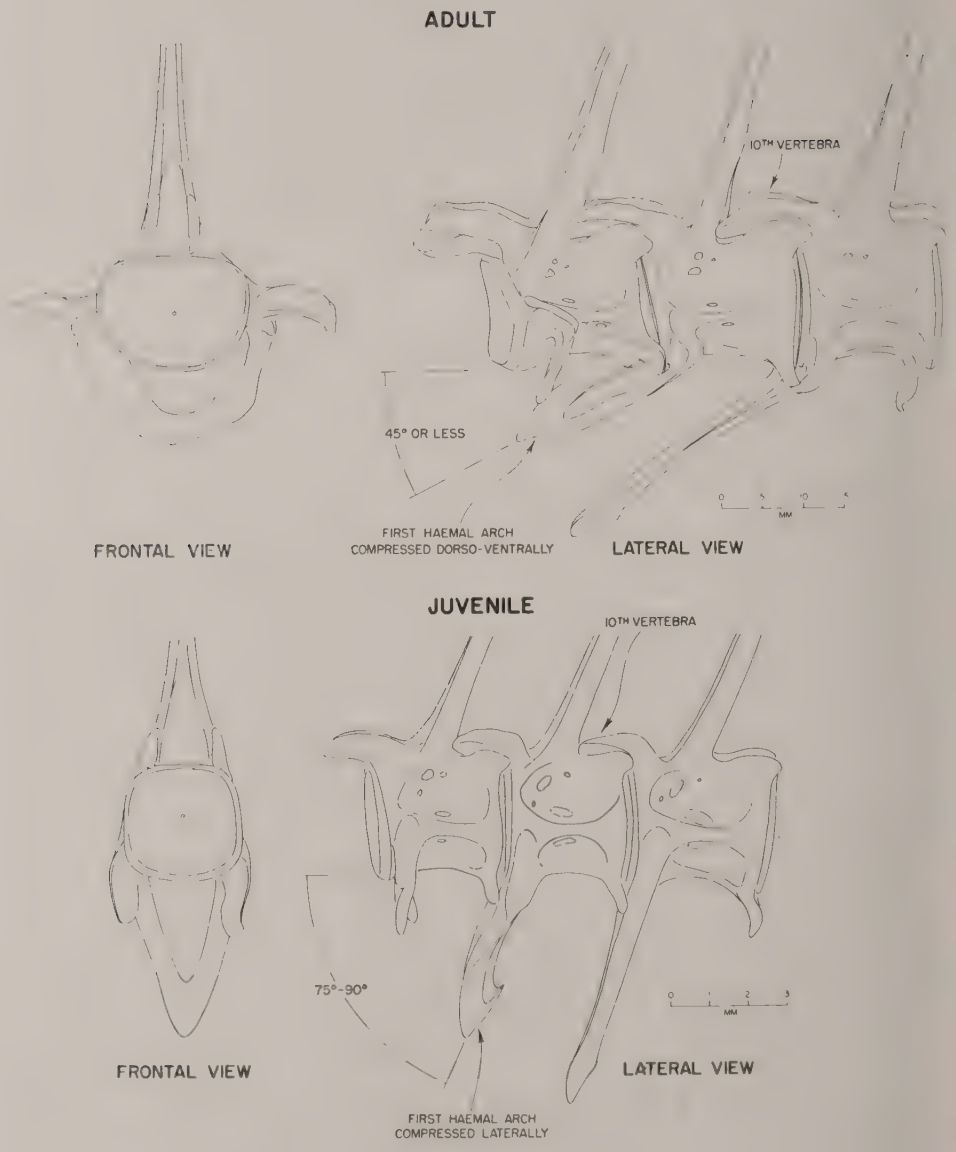

FIG. 4. First haemal arch of adult and juvenile albacore.

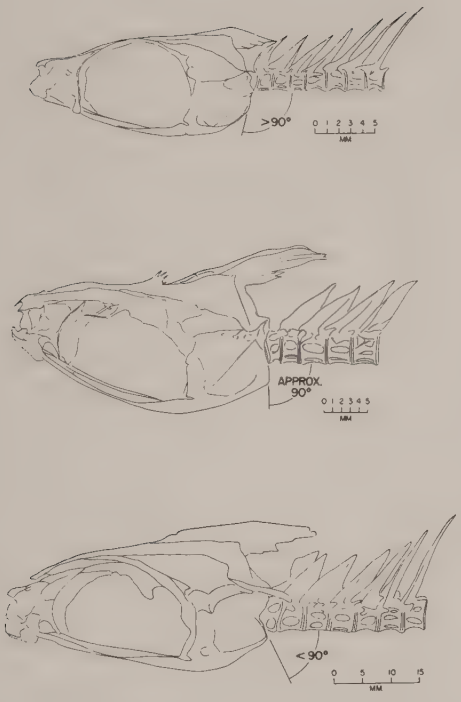

FIG. 5. Lateral view of skulls of juvenile albacore 88 mm (*top*), 184 mm (*center*), and 257 mm (*bottom*) in standard length.

a yellowfin, and one in the stomach of a wahoo (*Acanthocybium solandri*).

The occurrence of juvenile albacore in the Pacific Ocean is shown in Figure 6. Previously juvenile albacore were recorded from 18°38′N, 151°26′ E and 20°57′ N, 149°36′ E in the western North Pacific and 18°44′ S, 176°54′ E, 18°58′ S, 176°27′ E and 20°50′ S, 155°20′ E in the central and western South Pacific (Yabe et al., 1958). The discovery of the 12 juvenile albacore reported here establishes a new eastward distribution record for juveniles in the Pacific Ocean. The known distribution of juvenile albacore now extends as far east as the Hawaiian Islands in the North Pacific and as far as 162° W longitude in the South Pacific.

Although the number of specimens is small, the discovery of juvenile albacore in these areas supports the findings of past studies on albacore spawning based on gonad condition and also provides positive evidence of spawning. It had been hypothesized that albacore in the North Pacific spawn in a broad area extending westward from the Hawaiian Islands (Ueyanagi, 1957; Otsu and Uchida, 1959). Similarly, in the South Pacific (also on the basis of gonad studies) Otsu and Hansen (1962) indicate that albacore may spawn in a broad area north of 20° S. It can be seen in Figure 6 that juvenile

TABLE 2

JUVENILE ALBACORE FOUND IN STOMACHS OF PREDATORS

SPECIMEN NO.	DATE	LOCALITY	STANDARD LENGTH	PREDATOR
1	8-11-60	23°46′ N, 171°02′ E	131 mm*	blue marlin
2	8-11-60	23°46′ N, 171°02′ E	131 mm*	blue marlin
3	2-25-62	10°43′ S, 178°46′ E	85 mm	blue marlin
4	2-26-62	13°25′ S, 179°15′ W	61 mm*	yellowfin
5	2-26-62	13°25′ S, 179°15′ W	75 mm*	yellowfin
6	3-13-62	15°35′ S, 171°16′ W	88 mm	blue marlin
7	3-24-62	06°32′ S, 162°45′ W	74 mm	wahoo
8	8- 1-62	off Kona, Hawaii	184 mm	blue marlin
9	8-13-62	off Waianae, Oahu	135 mm*	striped marlin
10	9-13-62	off Waianae, Oahu	184 mm*	blue marlin
11	11- 2-62	off Waianae, Oahu	257 mm	striped marlin
12	11- 2-62	off Waianae, Oahu	283 mm*	striped marlin

* Estimated.

FIG. 6. Occurrence of juvenile albacore in the Pacific Ocean. Based on collections of Biological Laboratory, Honolulu, Hawaii (*stars*) and data in Yabe et al. (1958) (*triangles*). Figures in parentheses are numbers of specimens.

albacore have been captured in widely scattered areas in tropical and subtropical waters extending from approximately 150° E to 155° W in the North Pacific and 155° E to 162° W in the South Pacific. It would be interesting to discover whether albacore spawn randomly in these broad areas or whether there is concentrated spawning within them.

SUMMARY

Stomachs of large pelagic fishes collected during the period June 1960 through November 1962 were examined for the occurrence of juvenile albacore. The stomachs were obtained from fishes landed by the Hawaiian commercial longline fishery, captured during cruises of the research vessel "Charles H. Gilbert," and captured during the 1962 Hawaiian International Billfish Tournament at Kona, Hawaii.

Twelve juvenile albacore were discovered in the stomachs of predators: six from five blue marlin, three from three striped marlin, two from a yellowfin tuna, and one from a wahoo.

The juveniles were identified on the basis of the haemal spine on the first caudal vertebra, which in the albacore has a unique laterally flattened shape. The smallest specimen identified by this character measured an estimated 61

mm in standard length. Other supplementary characters confirmed the specimens as being albacore. The juveniles were described and counts and measurements were made.

The flattened haemal spine and full adult complement of gill rakers are developed relatively early in the life of the albacore. Certain other morphological features, including the angle the posterior margin of the basioccipital makes with the axis of the vertebral column, the orientation of the parapophyses on the vertebrae preceding the ninth vertebra, the orientation of the bones of the first haemal arch, and the angle the first haemal arch makes with the axis of the vertebral column, seem to develop more slowly and assume their adult form later in the life of the albacore.

A new distribution record for juvenile albacore was established with the discovery of these juveniles, demonstrating new or extending known spawning grounds for albacore in the Pacific Ocean. These captures of juvenile albacore support the conclusions of studies made on albacore spawning based on gonads, which indicated that albacore spawn in broad areas of the tropical and subtropical waters of the North and South Pacific Oceans.

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NOTES ON SCHOOLING BEHAVIOR, SPAWNING, AND MORPHOLOGY OF HAWAIIAN FRIGATE MACKERELS, *AUXIS THAZARD* AND *AUXIS ROCHEI*.—Twelve *Auxis thazard* (Lacépède) and 18 *Auxis rochei* (Risso) were caught by pole-and-line on 30 and 31 August 1962 about a mile offshore the island of Oahu. Fork lengths ranged from 32.4 to 36.2 cm for *A. thazard* and from 29.2 to 32.9 cm for *A. rochei*. Schooling and spawning observations were made at sea. Observations on ovaries and morphology were made in the laboratory.

The occurrence of *A. thazard* in Hawaii has been known for many years, but the occurrence of a second species of frigate mackerel, *A. thynnoides*, in Hawaii was

Fig. 1. Dorsal view of skull of *Auxis rochei* (left) and *A. thazard* (right).

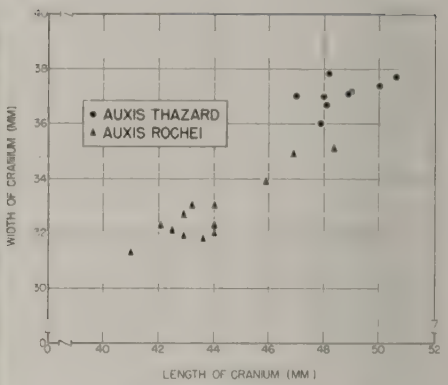

Fig. 2. Relation between the width and length of the cranium of *Auxis thazard* and *A. rochei*. Width: distance between widest points of pterotic processes. Length: distance from anterior margin of vomer to concave ventral tip of aperature of myodome.

recorded for the first time in 1960 (Matsumoto, Pac. Sci. 14 (2) :173–177). *A. thynnoides* has been assigned to *A. rochei* on the basis of priority by Fitch and Roedel (1963, Proc. World Sci. Meet. Biol. Tunas, FAO Fish. Rept. 6, 3:1329–1342), who reviewed the frigate mackerels of the world and concluded that only 2 valid species exist: *A. thazard*, from the Pacific Ocean, and the cosmopolitan *A. rochei*. We have followed the nomenclature of Fitch and Roedel and refer the narrow-corseleted frigate mackerel to *A. thazard* and the wide-corseleted frigate mackerel to *A. rochei*.

Our specimens were located at sea on both days by sighting a large flock of birds flying above what appeared to be a single large school. As we approached the area, it became evident that the flock was composed of many smaller units, each unit hovering and flying separately, presumably over a smaller school of fish. Many unsuccessful attempts were made to bring these small schools to the stern of our vessel by chumming with live bait. Usually, the fish appeared momentarily at the stern and then disappeared. On 3 occasions, schools remained long enough for fish to be caught. On the first day, a single *A. thazard* was caught from one school, and 18 *A. rochei* were caught from another school. On the next day, 11 *A. thazard* were caught from the only school successfully brought to the stern of the vessel by chumming.

The schools of *Auxis* were encountered in the same area on both days, about a mile offshore of Kaena Point, Oahu. On both days, a relatively sharp line was visible where the smooth water of the leeward area met the rough water of the windward area. The schools seemed to be concentrated in the proximity of this boundary and often crossed from one side to the other.

Milt was observed to be flowing from the vents of males of both species when they were landed on the deck of the vessel. Unsuccessful attempts were made to press ova out of the females for artificial fertilization. Subsequent examination of the females revealed ovaries that were flaccid, translucent, and grayish like those seen in spent female yellowfin tuna (*Thunnus albacares*) (June 1953, U. S. Fish Wild. Serv. Fish. Bull. No. 77, 54:47–64).

Ovaries from 8 *A. thazard* and 5 *A. rochei* were examined in the laboratory. Both species had ova in stages of resorption. These ova were similar in appearance to those of yellowfin tuna (Yuen and June 1957, U. S. Fish Wildl. Serv. Fish. Bull. No. 112, 57:251–264). One specimen of *A. thazard* still had residual ova free in the lumen. Measurements of the greatest diameter of 40 of these ova ranged from 0.75 to 1.30 mm and averaged 1.08 mm. Free residual ova were not found in *A. rochei*. In *A. thazard*, 2 size groups of primordial ova were present, one group ranging from 0.07 to 0.10 mm in

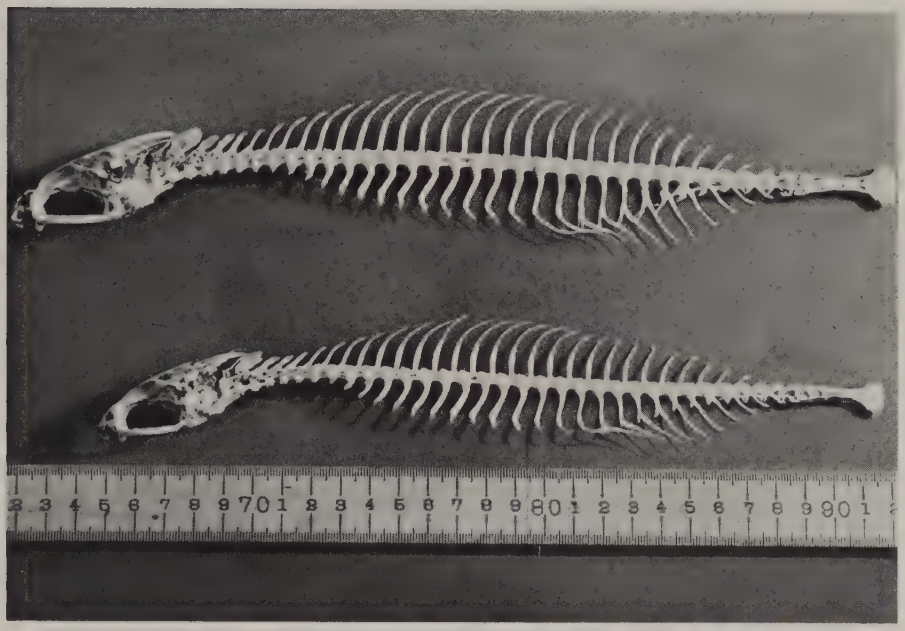

Fig. 3. Lateral view of skeleton of *Auxis thazard* (top) and *A. rochei* (bottom).

diameter and the other, which were few in number, ranging from 0.17 to 0.22 mm in diameter. In *A. rochei*, only primordial ova ranging from 0.07 to 0.08 mm in diameter were seen.

Both Matsumoto (1958, U. S. Fish Wildl. Serv. Fish. Bull. No. 128, 58:31–72) and Strasburg (1959, J. Cons. int. Explor. Mer 24 (2) :254–263) reported the occurrence of larval *Auxis* during June, July, and August in Hawaiian waters. Our capture of ripe males and spent females provides further circumstantial evidence of summer spawning in these waters for these species.

Gill raker counts of 9 *A. thazard* were 9–10 + 1 + 29–31 = 39–42 and of 13 *A. rochei* were 10–11 +1 +33–37 = 44–49. These are similar to counts obtained for Hawaiian specimens by Matsumoto (1960, *op. cit.*), for Japanese specimens by Kishinouye (1923, J. Coll. Agric., Tokyo 8 (3) :293–475), and for Philippine specimens by Wade (1949, U. S. Fish Wildl. Serv. Fish. Bull. No. 46, 51:229–240). In specimens from the eastern Pacific Ocean, however, Fitch and Roedel (*op. cit.*) obtained similar counts for *A. rochei* but higher counts for *A. thazard* (9–12 + 1 + 30–36 = 41–47).

Godsil (1954, Calif. Dept. Fish Game, Fish Bull. 97:1–185) noted that the temporal crests of the skull of *A. rochei* are parallel with each other and with the supraoccipital crest, while in *A. thazard* the temporal crests diverge anteriorly, so that the 3 crests are not distinctly parallel. We found a few *A. rochei* with temporal crests that diverged slightly at the anterior end. However, the divergence was not as great as in *A. thazard*. The angle which the temporal crests made with a line parallel to the supraoccipital crest ranged from 0° to 2° in *A. rochei* and 3° to 7° in *A. thazard* (Fig. 1). Godsil also noted that the skulls of *A. thazard* were wider than those of the other species. Similar measurements of skull width and skull length of our specimens are shown in Fig. 2. The *A. thazard* in our collection were generally larger than the *A. rochei*, but in the 2 instances where the skull lengths did overlap, the skulls of *A. thazard* were wider than those of *A. rochei*. Differences in the configuration of the ethmoid, myodome, and orbit were variable in our specimens and were not useful for separating the species.

The most striking difference in the axial skeleton of our specimens was the length of

the anterior branch of the hemal processes. In *A. thazard*, these processes were much longer and were in contact with the preceding hemal arches on the 24th to 28th vertebrae. In *A. rochei*, the anterior branches of the hemal processes were short, more fragile, and were never in contact with the preceding hemal arches (Fig. 3). In Japanese and Indo-Pacific specimens, these processes have been reported as being much longer in *A. thazard* by Kishinouye (*op. cit.*) and Watanabe (1962, Rep. Nankai Reg. Fish. Res. Lab. 16:155–171). These authors did not report anything concerning contact between the hemal processes and the arches.

We have found these morphological differences to be useful in the identification of partially digested specimens of Hawaiian frigate mackerels obtained from stomachs of their predators.

Our thanks are due John E. Fitch and Phil M. Roedel for reviewing the manuscript of this note.—Howard O. Yoshida and Eugene L. Nakamura, *U. S. Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii.*

Reprinted from Biological Bulletin, Vol. 129, No. 1, 199–216, August, 1965
Printed in U. S. A.

GROWTH AND SURVIVAL OF POSTLARVAL PENAEUS AZTECUS UNDER CONTROLLED CONDITIONS OF TEMPERATURE AND SALINITY [1]

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Temperature and salinity may be considered among the most important abiotic factors influencing the growth and survival of much of the estuarine fauna. They are of particular significance to those organisms that spend certain portions of their life cycle in the open sea where both factors are relatively stable, and other portions in the estuarine areas where both temperature and salinity may change drastically. Although temperature is generally thought to overshadow salinity in its effects on migratory organisms, salinity, probably through its osmotic effects, also plays a part in limiting some organisms to specific environments.

Several investigators have attemped to evaluate the importance of temperature and salinity to penaeid shrimp of the Gulf of Mexico, but ecological questions concerning these factors remain unanswered. Although field studies have dealt with the relationship of shrimp to salinity, the conclusions reached have differed widely enough to warrant further investigation. The interpretation of observations on salinity and shrimp abundance in nature is made difficult by changes in other environmental factors, some of which frequently vary with salinity. Such factors include temperature, light, substrate, food supply, cover and pollution. For this reason, controlled-environment studies in the laboratory were employed in the present work.

In an earlier study, Zein-Eldin (1963) determined that under conditions of constant temperature and somewhat restricted food supply, grooved *Penaeus* postlarvae [2] survived and grew over a wide range of salinity (2–40‰). However, it has been suggested that in other migratory Crustacea, notably in the European shrimp, *Crangon crangon* (Broekema, 1941), as well as in juvenile and adult brown and pink shrimp, *Penaeus aztecus* and *P. duorarum,* respectively (Williams, 1960), temperature can influence tolerance to salinity. Thus, further studies were designed to test the combined effects of temperature and salinity on the survival and growth of postlarval brown shrimp.

Materials and Methods

The work was of two types, 24-hour survival studies and a 28-day growth experiment. For all work, postlarval brown shrimp of approximately 12 mm. rostrum-telson length were seined from the Gulf of Mexico surf at the entrance to Galveston Bay. The animals were held in the laboratory in aerated water of ap-

[1] Contribution No. 205, Bureau of Commercial Fisheries Biological Laboratory, Galveston, Texas.

[2] As defined by Renfro (1964).

proximately 25‰ and 25° C. for at least 24 hours prior to use. Few mortalities occurred during this preliminary holding period.

The first objective was to obtain a rapid, crude estimate of postlarval tolerance to salinity and temperature in order to provide guidelines for the more detailed and sensitive growth study to follow. Accordingly, we selected short-term survival as a rough index suited to our needs.

To determine the short-term tolerance of brown shrimp to salinity and temperature, we exposed groups of experimental shrimp to different levels of the two factors for 24 hours. The test levels were chosen to include and extend above and below the ranges of salinity and temperature at which large numbers of postlarvae have been observed in nature (Bearden, 1961; Williams, 1955; Baxter, unpublished).

Temperature control of ±0.5° C. was maintained by B.O.D.-type incubators. Salinity changes were effected by replacing portions of water in the test containers with equal volumes of either distilled water or evaporation-concentrated sea water. Salinity was determined by hydrometer and reported to the nearest part per thousand. Four series of 24-hour survival experiments were carried out with groups of 5 to 30 animals as described below. Series 1, 2 and 4 had an initial salinity of 24–25‰ and an initial temperature of 24° to 26° C., matching conditions of the holding aquaria. Initial salinity in Series 3 was 40‰, equal to the unusually high level at which animals for that series were collected. Following introduction of the shrimp into the vigorously aerated experimental containers, stepwise changes in both temperature and salinity (0 to 8 steps, depending on the magnitude of change involved) were made over a 10- to 12-hour period, to reach the desired conditions. The attainment of these conditions marked the beginning of the 24-hour test period. At the end of that time, the beakers were removed from the incubators and the live and dead postlarvae counted. Failure to show either spontaneous or probe-induced activity upon return to room temperature was considered indicative of death. No food was provided during the experiment.

Previous observations of postlarvae in the laboratory had indicated that failure to keep them under water mechanically could lead to considerable mortality, due to their jumping activity. This type of loss was avoided during the first two series by restraining each group of animals in a one-liter beaker whose mouth was filled with a stemless funnel 4 inches in diameter. When the beaker was filled with water, all air space accessible to the shrimp was eliminated, thereby preventing the animals from escaping the vessel or adhering to its dry surfaces. Aeration was provided by means of an air stone attached to $\frac{3}{16}$-inch O.D. Tygon tubing fitted through the hole in the funnel.

In the first two series, we employed only five shrimp per group, hoping thus to reduce cannibalism. Although losses caused by escape from the water were successfully avoided, test results indicated that cannibalism occurred at intermediate and higher temperatures where the number of survivors plus the number of dead animals remaining per group frequently totaled less than the original number of shrimp (Table I). In such cases, we attempted to discriminate between deaths due to cannibalism and mortalities attributable to salinity and temperature by arbitrarily assuming that salinity-temperature combinations causing the rapid death of some experimental shrimp were sufficiently severe to inhibit feeding, including cannibal-

TABLE I

Survival of P. aztecus postlarvae after 24-hour exposure to various combinations of salinity and temperature

Series no.	Shrimp per group	Acclimated for: (hrs)	Experimental conditions																							
1	5	10–12	Temperature (° C.)	7					15					25					30					35				
			Salinity (‰)	3	8	23	32	36	5	10	24	34	37	5	11	25	34	37	6	10	26	36	41	7	11	27	36	37
			Survivors	0	1	5	5	4	1	4	5	5	5	3	4	5	5	5	4	4	4	5	4	1	2	1	1	3
			Intact dead*	5	4	0	0	1	4	1	0	0	0	0	0	0	0	0	0	1	0	0	0	4	1	2	3	1
2	5	10–12	Temperature (° C.)	7					15					25					30					36				
			Salinity (‰)	5	9	24	34	38	4	9	24	34	38	4	8	24	34	38	4	9	24	33	37	4	9	25	34	39
			Survivors	0	2	5	5	4	0	3	5	5	5	4	4	5	5	4	3	3	5	4	5	0	1	1	3	2
			Intact dead*	5	3	0	0	1	5	2	0	0	0	0	0	0	0	1	0	0	0	0	0	5	3	4	0	2
3	10	10–12	Temperature (° C.)	7					15					25					31					34				
			Salinity (‰)	6	10	25	36	37	7	11	26	34	38	7	10	26	35	39	6	11	26	34	39	7	11	26	35	39
			Survivors	0	6	10	10	10	8	10	10	10	10	8	10	10	10	10	10	10	10	10	10	9	9	10	10	10
4	30	10–12	Temperature (° C.)	10					25					34														
			Salinity (‰)	10			39		25					11			41											
			Survivors	26			28		30					28			30											
—	30	0	Temperature (° C.)	10										34														
			Salinity (‰)	11			39							11			41											
			Survivors	5			0							18			26											

* These were dead shrimp which showed no signs of having been eaten by the other experimental animals within the group. See text.

ism, among the survivors. High rates of penaeid activity, including movement, feeding, and molting, have been observed at temperatures of 25° and 32° C. in this laboratory. Such activities favor cannibalism among shrimp under relatively crowded experimental conditions. On this basis, we counted as mortalities only those dead animals visibly present at the end of each 24-hour experimental period.

To test this assumption, we required data unaffected by cannibalism. These were obtained in Series 3 by confining each animal within a 1½-inch length of 14-mm. Pyrex tubing, both ends of which were covered with cotton gauze held in place with small rubber bands. While permitting contact between the animal and its experimental aquatic environment, this procedure prevented "jump-out" losses and made physical contact between shrimp impossible. Ten postlarvae thus isolated were placed in each test beaker and the experimental conditions established as before. The survival results agreed well with those of the two earlier series as interpreted above, tending to substantiate our assumption regarding the effect of cannibalism.

TABLE II

Schedule of salinity and temperature changes [initial salinity and temperature were 26‰ and 23° C., respectively]

Elapsed time (hr.)	Desired salinity (‰)					Desired temperature (° C.)			
	2	5	15	25	35	11	18	25	30
	Actual salinity					Actual temperature			
2	20	20	20	25	25	23	23	23	26
8	15	15	15	25	30	19	22	24	30
24	10	10	15	25	35	17	19	25	33
36	5	5	15	25	35	12	18	25	33
48	2	5	15	25	35	11	18	25	32

In a fourth series, further survival data were sought at temperature-salinity combinations which seemed to be near the extremes of postlarval tolerance, as suggested by results of the three previous series (Table I). In this series the importance of acclimation was also estimated. Each set of experimental conditions was duplicated in two two-liter beakers, one for shrimp acclimated as usual, the other for animals which were transferred directly from the holding tank to the extreme salinity and temperature levels to be tested. Thirty individually confined postlarvae were held in each beaker, and 24-hour survival determined as before.

For the growth study, 46 liters of brackish water and 100 animals were placed in each of twenty 15-gal. aquaria. Filtration, aeration, and confinement were accomplished as previously described (Zein-Eldin, 1963). Five aquaria were placed in each of four constant-temperature rooms. The experimental temperatures were changed from the initial 23° C. to 11°, 18°, 25°, or 32° C. Water temperature, although ±0.5° C. in a given aquarium, varied as much as 1° C. among aquaria in a single room. The initial salinity of 23‰ was simultaneously adjusted stepwise with temperature, to final levels of 2‰, 5‰, 15‰, 25‰, or 35‰ (Table II). Each tank was continuously illuminated by two 40-w. fluorescent lamps.

Postlarvae were fed live brine shrimp (*Artemia*) nauplii throughout the growth experiment. The nauplii in a 0.1-ml. sample of brine shrimp in water were counted to estimate number per unit volume, and the volume of food recorded at each feeding of the postlarvae. *Artemia* nauplii were filtered and washed with distilled water before their addition to the tanks, in order to avoid increases in experimental salinity levels. Live brine shrimp nauplii were present in excess in all aquaria during the first 24 days of the experiment. During the last four days at 32° C., however, the shrimp had grown to such a size that maintaining an excess food supply became almost impossible, even though 400,000 to 500,000 nauplii per tank (a minimum of 9000 to 10,000 per experimental animal) were supplied per day.

TABLE III

Cumulative mortality [only observed deaths are included]

Elapsed time (days)	Temperature (° C.) Salinity (‰)	32				25					18					11				
		2	5	15	25	35	2	5	15	25	35	2	5	15	25	35	2	5	15	25	35
1		5	1	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0
2		41	25	16	2	0	0	0	0	0	0	2	2	0	0	0	4	2	0	0	0
3		44	25	16	6	0	0	0	0	0	0	13	3	0	0	0	77	2	0	0	0
4		45	25	17	7	0	0	0	0	0	0	17	3	0	0	0	93	5	0	0	0
5		45	25	17	7	0	0	0	0	0	0	19	3	0	0	0	97	12	0	0	0
6		45	25	17	7	0	0	0	0	0	0	19	3	0	0	0	97	12	0	0	0
7		45	25	17	7	0	0	0	0	0	0	19	3	0	0	0	97	22	0	0	0
8		45	25	17	7	0	0	0	0	0	0	19	3	0	0	0	97	25	0	0	0
9		45	25	17	7	0	0	0	0	0	0	19	3	0	0	0	97	32	0	0	0
10		45	25	17	7	0	0	0	0	0	0	19	3	0	0	0	97	37	0	0	0
11		45	25	17	7	0	0	0	0	0	0	24	3	0	0	0	97	41	0	0	0
12		45	25	17	7	0	0	0	0	0	0	26	4	0	0	0	97	45	0	0	0
13		45	25	17	7	0	0	0	0	0	0	27	4	0	0	0	97	50	0	0	0
14		45	25	17	7	0	0	0	0	0	0	27	4	0	0	0	97	55	0	0	0
17		45	25	17	7	0	0	0	0	0	0	29	4	0	0	0	97	60	0	0	0
18		45	25	18	7	0	0	0	0	0	0	31	4	0	0	0	97	60	0	0	0
19		45	25	18	7	0	0	0	0	0	0	45	4	0	0	0	97	60	0	0	0
20		46	25	18	7	0	23	0	0	0	0	57	4	0	0	0	97	63	0	0	0
21		46	25	18	7	0	39	0	0	0	0	58	5	0	0	0	97	63	0	0	0
22		46	25	18	7	0	50	0	0	0	0	58	5	0	0	0	97	63	0	0	0
24		46	25	18	7	0	55	0	0	0	0	58	5	0	0	0	97	66	0	0	0
28		46	25	18	7	2	55	0	0	0	0	58	5	0	0	0	97	67	0	0	4
No. of animals removed for measurement		25	30	35	50	50	40	50	50	50	50	36	50	50	50	50	0	30	50	50	50
No. escaped		2	0	0	0	0	4	4	3	0	0	1	2	2	2	0	0	0	0	0	0
Observed survivors		15	22	25	29	47	0	43	43	50	49	0	41	46	48	49	0	0	49	46	43
Unobserved deaths		12	23	22	14	1	1	3	4	0	1	5	2	2	0	1	3	3	1	4	3
Per cent survival		21	31	38	58	94	0	93	91	100	98	0	85	96	100	98	0	0	98	92	86

At approximately 5-day intervals, 10 animals were removed from each aquarium. These included both the largest and smallest specimens, and eight collected at random. The animals were individually measured to the nearest 0.5 mm., blotted dry, weighed to the nearest 0.1 mg. with a Mettler H15 analytical balance, and preserved. At the termination of the experiment, all remaining animals were similarly treated. The final per cent survival was determined by comparing the total number of shrimp remaining at the close of the experiment to the number that theoretically should have been present (original number less those that had been removed for sampling and a few that had escaped). The unobserved deaths recorded in Table III were animals not accounted for either as survivors, observed deaths, or those sampled for measurement.

On the assumption that an individual *Artemia* nauplius weighs an average of 7.1 μg. (D. Godwin, unpublished), we estimated conversion efficiency by comparing the calculated wet weight of the brine shrimp that were fed with the weight

gain of the surviving penaeids. Determinations were made only for those temperature and salinity combinations at which survival was 85% or greater.

Although the design of the experiment was similar to that of Costlow, Bookhout and Monroe (1960, 1962) in studies of larval crab survival, we did not use the statistical methods which they employed. The fitted-surface method of Box and Youle (1955) has proved valuable in industrial applications of physical and chemical interactions whose principles are sufficiently well defined to permit relatively safe

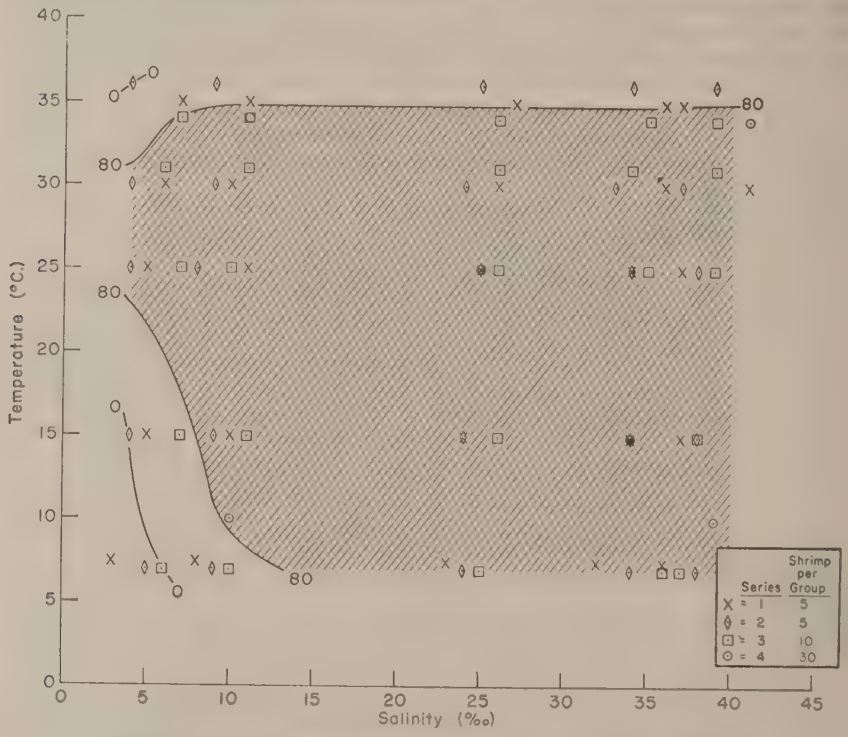

FIGURE 1. Per cent survival of *P. astecus* postlarvae after 24 hours at indicated levels of salinity and temperature.

extrapolation from a limited number of experimental observations. However, the complex nature of biological responses to temperature and salinity renders such extrapolation extremely speculative. In the present study, we have tested a group of temperature-salinity combinations which represents a relatively large range of levels for each factor. Our interpretations of the results exclude extrapolation.

RESULTS AND DISCUSSION

Short-term survival

The excellent survival of postlarvae for periods of 24 hours under most of the experimental conditions suggested a broad zone of short-term tolerance to both

salinity and temperature (Table I). The animals were quite euryhaline, especially at 25° and about 30° C., although a marked reduction in tolerance to salinity levels below 10‰ was demonstrated at 7° and 15° C. (Fig. 1). A general reduction in survival near 35° C., regardless of salinity, suggests a strong temperature effect. The absolute limiting (maximum) temperature for *P. aztecus* is probably only slightly above 35° C.

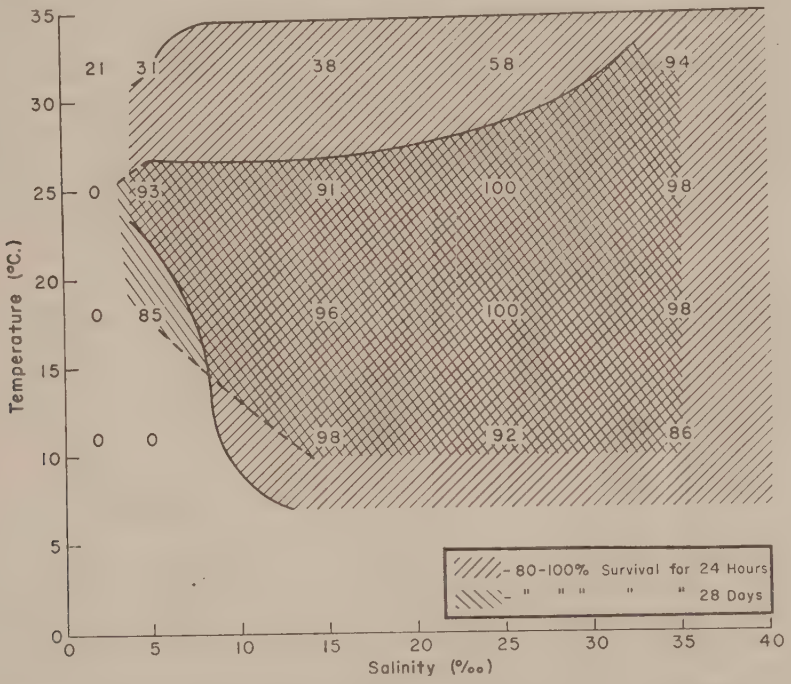

FIGURE 2. Long- and short-term survival of *P. aztecus* at indicated levels of salinity and temperature. Numbers indicate 28-day survival in per cent.

The effect of acclimation in extending ranges of postlarval tolerance is clearly shown in the results of the fourth series. In each of the four combinations of temperature and salinity, gradually changed conditions permitted better survival than did sudden changes (Table I). This effect was considerably more marked at 10° than at 35° C.

28-Day survival

The survival of postlarvae in the 28-day experiment further confirmed this wide zone of tolerance to salinity and temperature. Although the per cent survival for 28 days was somewhat lower than that observed for only 24 hours, in most cases the results were much the same (Fig. 2). There is some suggestion of greater long-term survival for animals at low temperature and low salinity than

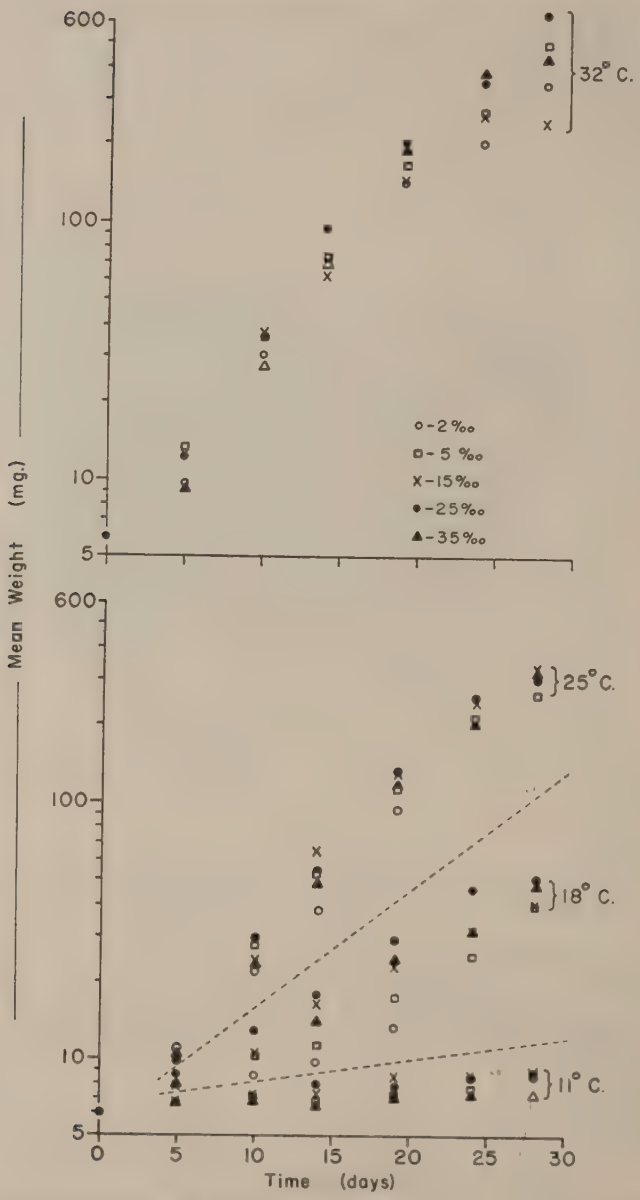

FIGURE 3. Growth of young *P. aztecus* at indicated levels of temperature and salinity.

for those exposed only 24 hours. This apparently paradoxical situation is probably related to the longer acclimation period employed in the 28-day study.

Survival was markedly reduced at the highest temperature (32°C.) at all salinities tested except 35‰. Much of the accountable mortality at this temperature occurred during the first four days (Table III) and was presumably the result of the immediate stress caused by the changes in environment. However, the stress of salinity acclimation would not seem to explain the poorer survival observed at 25‰ (very near the initial salinity) than at 35‰. The relatively large numbers of unobserved deaths occurring at 32° C. and 2‰, 5‰, 15‰ and 25‰ (Table III) suggest two other possible causes of mortality—the experimental temperature *per se*, and increased cannibalism associated with high temperatures (as noted above in Series 1 and 2 of the 24-hour studies). It is possible that at 32° C. the one-month period of exposure in the growth experiment elicited long-term temperature effects which could not be manifested in the relatively short duration of the 24-hour studies.

TABLE IV

Increase in mean length (mm.) of P. aztecus surviving 28 days at indicated levels of temperature and salinity

Temperature (° C.)	Salinity (‰)				
	2	5	15	25	35
32	23.4	28.9	19.0	32.0	25.8
25	—	21.9	24.4	22.3	22.6
18	—	6.3	6.5	7.4	7.6
11	—	—	0.5	0.5	0.4

Mortalities occurring at other temperatures were limited to the lowest salinities, with stress due to reduced salinity and temperature being sufficient to kill all the animals at 2‰ and 11° C. in only 5 days (Table III). The mortalities observed at 5‰ and 11° C., as well as those at 2‰ and 18° C., probably reflect the cumulative effects of stress, since deaths occurred continuously throughout the course of the experiment. At 25° C. and 2‰, however, all observed deaths occurred during a four-day period late in the experiment. Although the initial cause of this mortality is not known, later deaths (on the 21st through the 24th day) were probably due to fouling of water, since brine shrimp were also dying. Furthermore, an earlier experiment (Zein-Eldin, 1963) had indicated that *P. aztecus* postlarvae survive well under these conditions.

Growth

Differences in rate of growth were more closely related to temperature than to salinity (Fig. 3). The relative effects of the two factors may be readily determined by comparing the magnitude of growth differences associated with variation in salinity (columns) with that due to variation in temperature (rows) (Table IV). Differences in mean length between temperature groups were detectable as early as the first sampling period (5 days) and increased in magnitude during the experi-

mental period (Fig. 4). Both length and weight increased much more rapidly at 32° and 25° C. than at lower temperatures. The maximum increase in size was observed at 32° and 25‰ conditions under which one animal grew to 50 mm. and 962 mg., a more than four-fold increase in length and a weight increase of 150-fold (Table V). The great variation in size noted earlier (Zein-Eldin, 1963) was also observed in this experiment, with differences in length between smallest and largest

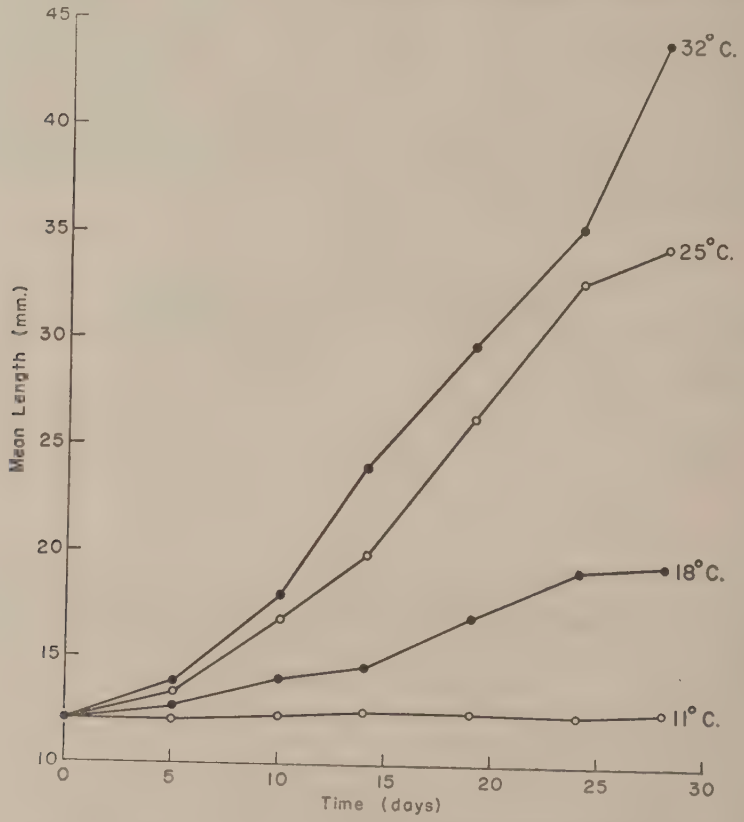

FIGURE 4. Growth of young *P. astecus* at various temperatures (salinity: 25‰).

animals ranging from 13 to 25.5 mm. in the various salinities at 25° and 32° C. (Table V). Almost no growth was detected at 11° C., although survival was good at salinities of 15‰ and above. With the exception of 32° C. and corresponding salinity levels of 25‰ and below, where mortality more than offset the rapid growth rate (Tables IV and VI), the gain in total weight of the survivors was comparable within a temperature. However, this gain increased approximately 10-fold within each level of salinity between 11° and 18° C., and only slightly less between 18° and 25° C. (Table VI).

TABLE V

Mean size and growth rate of growth-experiment survivors, including 10 animals sampled at 28 days and shown in Table VII. Size range given in parentheses. Initial weight and length were 6.1 mg. and 12.1 mm., respectively

Temperature and salinity	Number of survivors	Weight (mg.)	Length (mm.)	Increase in length per day (mm./day)
32° C.				
2‰	15	340.6 (157.7–735.1)	34.8 (27.5–47.5)	0.81 (0.55–1.26)
5‰	22	447.6 (241.0–667.6)	39.6 (33.0–46.0)	0.98 (0.75–1.21)
15‰	25	240.2 (35.2–542.0)	31.0 (17.0–42.5)	0.68 (0.18–1.09)
25‰	29	610.8 (309.0–961.9)	43.1 (36.0–50.0)	1.11 (0.85–1.35)
35‰	47	423.7 (164.7–753.6)	38.3 (28.5–46.5)	0.94 (0.59–1.23)
25° C.				
5‰	43	274.0 (115.3–482.0)	33.9 (25.0–41.5)	0.77 (0.46–1.05)
15‰	43	375.3 (163.8–681.1)	37.4 (29.0–46.5)	0.90 (0.60–1.23)
25‰	50	313.8 (101.4–538.0)	35.2 (24.0–44.0)	0.82 (0.42–1.14)
35‰	49	291.0 (108.0–605.7)	34.4 (24.5–43.0)	0.80 (0.44–1.10)
18° C.				
5‰	41	33.9 (18.0– 56.2)	18.3 (14.0–21.5)	0.20 (0.08–0.34)
15‰	46	43.7 (15.3– 77.7)	19.1 (14.5–23.0)	0.25 (0.09–0.39)
25‰	48	52.8 (15.0–101.4)	20.1 (14.0–25.0)	0.29 (0.08–0.46)
35‰	49	35.2 (17.7– 62.7)	18.3 (14.5–22.0)	0.22 (0.09–0.35)
11° C.				
15‰	49	8.7 (5.2–13.1)	12.6 (11.0–14.0)	0.03 (0–0.08)
25‰	46	8.8 (6.4–10.8)	12.7 (11.5–14.0)	0.02 (0–0.08)
35‰	43	7.6 (5.5– 9.7)	12.4 (11.0–13.0)	0.01 (0–0.08)

Growth rate based only upon the steepest portions of the growth curves (*i.e.*, between the 10th and 28th days) approached a value of 1.4 mm. per day at 32° C. and 1.1 mm. per day at 25° C., as against the lower values of 1.1 mm. per day at 32° and 0.8 mm. per day at 25° C. over the entire experimental period (Fig. 4, Table VII). Although the mean growth rates reported here (Table V) for both 25° and 32° C. exceed the maximum of 0.56 mm. per day which Pearson (1939) reported for laboratory-held postlarvae of *P. brasiliensis* (probably *P. aztecus*), and the maximum of 1.35 mm. per day far exceeds his value, these rates do not

TABLE VI

Increase in total weight (g.) of P. aztecus surviving 28 days at indicated levels of temperature and salinity. Food conversion efficiency (%) indicated in parentheses where survival was 85% or greater

Temperature (° C.)	Salinity (‰)				
	2	5	15	25	35
32	4.7	9.6	5.8	17.5	19.6 (37)
25	—	11.5 (43)	15.9 (53)	15.4 (46)	14.0 (43)
18	—	1.2 (32)	1.7 (33)	2.2 (40)	1.6 (34)
11	—	—	0.1 (12)	0.1 (14)	0.1 (5)

approach that of postlarval white shrimp, *P. setiferus,* which grew an average of 2.1 mm. per day in pond experiments conducted by Johnson and Fielding (1956). A similarly low rate of growth for aquarium-held *Metapenaeus mastersii,* which ranged in carapace length from 1.9 to 7.0 mm., has been reported by Dall (1958). Laboratory animals grew only 10 mm. in total length per month at 24° to 28° C., as against a natural growth rate of 20 to 30 mm. per month.

Growth of our laboratory-held *P. aztecus* postlarvae likewise only approached that of slightly larger animals in the field. Viosca (1920) estimated a growth rate of approximately 25 mm. per month for *P. setiferus* in the length range 30 to 150 mm., while Gunter (1950) observed a rate of 25 to 40 mm. per month for the same species growing from 28 to 100 mm. Extrapolation of Lindner and Anderson's (1956) growth curve for white shrimp gives a rate of 1.50 mm. per day for shrimp between 20 and 65 mm. in length. Williams (1955) determined a rate of 1.7 mm. per day for *P. aztecus* growing from 37 to 102 mm., a rate also estimated by St. Amant, Corkum and Broom (1963) for 51- to 125-mm. specimens of this species. It must be noted, however, that these estimates were for shrimp at the upper end of the size ranges encountered in the studies described here.

Although the studies of conversion efficiency were necessarily crude, the resulting data indicated that the most efficient utilization of food occurred at 25° C. (Table VI). Because of the high mortality, no efficiencies could be calculated for shrimp held at 32° C. in salinities of 25‰ and lower. The conversion values should be considered maximal at the highest temperatures since some cannibalism probably occurred. However, efficiencies for the animals held at 11° C. are probably low since it was apparent that much of the food provided was not eaten. At this low temperature, the postlarvae were generally inactive, resting most of the time on the bottom.

Johnson and Fielding (1956), studying *P. setiferus* in aquaria during August (temperature not stated), found a mean food-conversion efficiency of 19% for juveniles (mean weight 0.9 to 2.1 g.) held one week at 18.5‰, as against an efficiency of 24% for juveniles (mean weight 0.7 to 2.1 g.) held one week at 34‰. All animals were fed at a rate of 10% of the initial body weight per day, a rate less than that provided in our experiments. The lower efficiencies determined by Johnson and Fielding may be due, in part, to the larger size of the animals held, since it has been shown in fishes (Kinne, 1960) that conversion efficiency decreases with increasing size. Furthermore, Johnson and Fielding obtained the maximum efficiency of 50% from a group of animals of 0.7 g. mean weight held at 34‰. This value compares favorably with those reported here for brown shrimp of mean weight 0.3 g. and less, and would indicate that rapidly growing young shrimp require 2 to 4 g. of utilizable food to produce 1 g. of tissue.

The decrease in growth rate of animals held at 32° C. and 15‰ is unexplainable. This group of animals consumed less food during the latter days of the experiment, even though excess food was present. If this decreased growth represented a long-term effect of the combined stresses of lowered salinity and increased temperature, it is strange that such a decrease did not occur among groups held at even lower salinities at this temperature. Interpretation of the combined effects of lower salinity with 32° C. on growth was complicated by the high rates of mortality among these groups.

TABLE VII

Mean animal weight (mg.) and length (mm.) at each salinity and temperature level. All individuals initially 6.1 (±0.2) mg. and 12.1 (±0.2) mm. Values are based on samples of 10 except those that are starred, which are based on samples of 5. The largest and smallest remaining animals in each test group were included in each sample. Figures in parentheses indicate one standard error

Temp. (° C.) and elapsed time (days)	Level of salinity (‰)									
	2		5		15		25		35	
	Weight	Length	Weight	Length	Weight	Length	Weight	Length	Weight	Length
32°										
5	9.7* (0.9)	13.1* (0.3)	13.5 (1.0)	14.0 (0.4)	12.4 (0.9)	13.8 (0.3)	12.1 (1.0)	13.8 (0.3)	9.3 (0.6)	12.8 (0.3)
10	31.1* (4.9)	17.4* (0.3)	35.9 (3.8)	17.6 (0.6)	37.8 (7.8)	17.8 (1.0)	36.8 (5.8)	18.0 (0.9)	28.1 (4.3)	16.6 (0.7)
14	74.7* (15.8)	22.3* (1.5)	75.8* (12.0)	23.0* (1.2)	62.2 (10.9)	20.8 (1.0)	94.6 (13.0)	24.0 (1.2)	70.2 (9.8)	21.5 (1.0)
19	144.5* (11.2)	27.1* (2.3)	167.3* (16.6)	28.3* (0.9)	148.2* (33.6)	26.6* (2.2)	206.5 (34.7)	29.8 (2.0)	195.8 (23.0)	30.1 (1.2)
24	209.3* (61.0)	30.0* (2.9)	271.3 (32.0)	33.4 (1.2)	265.1* (59.5)	32.2* (2.6)	356.8 (53.7)	35.4 (1.9)	379.6 (51.5)	36.4 (1.6)
28	347.7 (54.1)	35.6 (1.9)	482.3 (23.0)	41.0 (0.6)	246.9 (53.6)	31.1 (2.5)	654.0 (73.8)	44.1 (1.7)	437.2 (57.8)	38.0 (1.8)
25°										
5	9.7 (0.7)	13.1 (0.3)	10.4 (0.7)	13.4 (0.2)	10.8 (0.5)	13.3 (0.2)	11.1 (0.6)	13.4 (0.3)	10.5 (0.6)	13.0 (0.2)
10	21.8 (2.0)	15.9 (0.5)	27.9 (3.0)	17.0 (0.5)	23.0 (3.1)	15.8 (0.6)	29.9 (4.6)	16.8 (0.8)	23.0 (2.2)	16.1 (0.5)
14	37.9 (3.4)	18.4 (0.6)	51.1 (8.6)	20.0 (1.1)	64.7 (12.5)	21.2 (1.3)	54.0 (8.4)	19.9 (1.0)	48.3 (5.1)	19.6 (0.7)
19	93.2 (9.6)	24.0 (1.3)	113.7 (20.6)	24.9 (1.4)	126.7 (22.4)	26.1 (1.3)	132.4 (17.1)	26.4 (1.1)	118.6 (16.9)	25.4 (1.4)
24	—	—	217.0 (25.6)	31.1 (1.2)	245.1 (24.9)	32.4 (1.2)	257.8 (27.0)	32.8 (1.1)	202.7 (27.8)	30.6 (1.2)
28	—	—	264.4 (27.4)	33.0 (1.2)	357.1 (41.8)	36.6 (1.4)	302.0 (41.2)	34.4 (1.7)	321.3 (44.3)	34.8 (1.3)
18°										
5	6.5 (0.2)	12.7 (0.1)	7.5 (0.2)	12.8 (0.1)	8.0 (0.4)	12.8 (0.2)	8.6 (0.5)	12.7 (0.2)	7.9 (0.2)	12.6 (0.1)
10	8.7 (0.4)	12.8 (0.2)	10.0 (0.1)	13.1 (0.1)	10.5 (0.6)	13.2 (0.2)	12.9 (0.8)	14.0 (0.2)	10.4 (0.6)	13.6 (0.3)
14	9.7 (0.5)	13.2 (0.2)	11.4 (0.8)	14.0 (0.3)	16.5 (1.6)	15.0 (0.5)	17.7 (1.6)	14.6 (0.5)	14.0 (1.0)	14.0 (0.3)
19	13.2* (1.1)	14.1* (0.2)	17.4 (1.0)	14.7 (0.2)	23.0 (1.7)	16.0 (0.1)	29.0 (3.6)	17.0 (0.7)	24.2 (2.1)	15.8 (0.3)
24	—	—	25.1 (2.7)	16.1 (0.6)	31.8 (2.9)	17.8 (0.5)	46.0 (4.7)	19.2 (0.6)	31.2 (3.6)	17.6 (0.5)
28	—	—	40.1 (4.0)	18.4 (0.7)	40.6 (4.9)	18.6 (0.7)	49.9 (7.7)	19.5 (1.0)	47.4 (4.0)	19.8 (0.7)
11°										
5	—	—	6.7 (0.3)	12.0 (0.2)	6.7 (0.3)	12.1 (0.1)	6.4 (0.3)	12.1 (0.1)	6.8 (0.2)	12.4 (0.1)
10	—	—	7.1* (0.3)	12.4 (0.2)	7.0 (0.3)	12.0 (0.2)	7.2 (0.3)	12.2 (0.2)	6.9 (0.4)	12.3 (0.2)
14	—	—	6.9* (0.3)	12.3 (0.1)	7.3 (0.2)	12.5 (0.2)	8.0 (0.3)	12.5 (0.2)	6.5 (0.3)	11.9 (0.2)
19	—	—	7.3* (0.4)	12.4 (0.1)	8.6 (0.3)	13.0 (0.2)	7.8 (0.3)	12.4 (0.2)	7.2 (0.3)	12.3 (0.1)
24	—	—	7.7* (0.3)	12.6 (0.1)	8.7 (0.6)	12.6 (0.2)	8.3 (0.4)	12.4 (0.2)	7.2 (0.4)	12.4 (0.3)
28	—	—	—	—	8.7 (0.4)	12.6 (0.2)	8.6 (0.4)	12.6 (0.2)	7.3 (0.4)	12.5 (0.2)

Biological and ecological implications

Commercially important North American shrimp of the genus *Penaeus* spawn at sea. As shown for *P. setiferus,* the larvae develop in the open sea, migrate into the estuarine areas as postlarvae, remain in the less saline estuaries until they approach maturity, and then return to the sea (Weymouth, Lindner and Anderson, 1933; Burkenroad, 1934; Pearson, 1939). Various studies in the field have suggested that postlarval and juvenile *Penaeus* are associated with low salinities characteristic of the estuary, and that postlarvae require the lowest salinity for growth and survival (Gunter, 1945, 1950; Pearse and Gunter, 1957). Lindner and Anderson (1956) concluded, however, that size of white shrimp (juveniles and subadults) seemed more closely related to locale than to salinity. Gunter, Christmas and Killebrew (1964) have recently presented additional field data indicating differences in the natural distributions, with respect to salinity, of the three commercial species, *P. aztecus, P. duorarum,* and *P. setiferus.* In so doing, these authors have made certain assumptions. For example (p. 184): "If salinity meant nothing to these animals they would be evenly distributed relatively over the whole range, if food were available. The general food habits of shrimp are still largely unknown, but all indications are they are omnivorous feeders, and shrimp do find food over the full salinity range up to pure sea water, although the food doubtless changes with size." The fact that shrimp do apparently eat a variety of food does not, however, indicate that all such foods are of comparable nutritive value (Williams, 1959; Zein-Eldin, 1963). Furthermore, there is no evidence that food is equally available throughout the salinity range occupied by shrimp in nature. Only in a previous study (Zein-Eldin, 1963) and in the work reported here, has food been equally available to all animals regardless of salinity. The 24-hour survival experiments, as well as the growth study, indicated that for *P. aztecus* postlarvae, only extreme salinity conditions influence growth and survival. Even normal oceanic salinity is not sufficient to interfere with postlarval brown shrimp growth and survival when other factors (temperature, food supply, predation, oxygen, light, pollution, etc.) are kept relatively constant. In view of our results, we suggest that other factors, such as food or cover (which may themselves require relatively narrow salinity ranges), are of greater importance than salinity *per se* in determining distribution, growth, and survival of these animals.

In the present studies, both the survival and the growth data indicated that wide ranges of salinity and temperature were well tolerated by postlarval brown shrimp. The combination of low salinity and low temperature, however, was not favorable, either for survival or growth. That *P. aztecus* can withstand extreme conditions of both factors has been demonstrated in the field as well, although published records have been largely limited to occurrences of juvenile and adult forms (Gunter, 1950). Bearden (1961), who found postlarval brown shrimp at temperatures as low as 6.5° C., noted a marked decrease in their abundance following the sudden cold spell which resulted in this low-temperature value. Renfro and Baxter (unpublished) have reported live postlarvae at 12° C. and 31.0‰ as well as at 2° C. and 30.5‰, supporting our laboratory evidence that low temperatures can be survived when salinities are sufficiently high. Comparable data of postlarval occurrence in low-salinity areas are not yet available. Brown shrimp (size not stated) have also been reported in salinities as low as 0.8‰

(Gunter and Shell, 1958) in Louisiana, while Gunter and Hall (1963) report a 34- and a 38-mm. specimen at 0.22‰ in the St. Lucie estuary in Florida. No temperatures were reported with the latter data, however. It must be noted, nevertheless, that St. Amant, Corkum and Broom (1963) reported maximal spring abundance of postlarval brown shrimp in Louisiana bays only after water temperatures consistently exceeded 20° C.

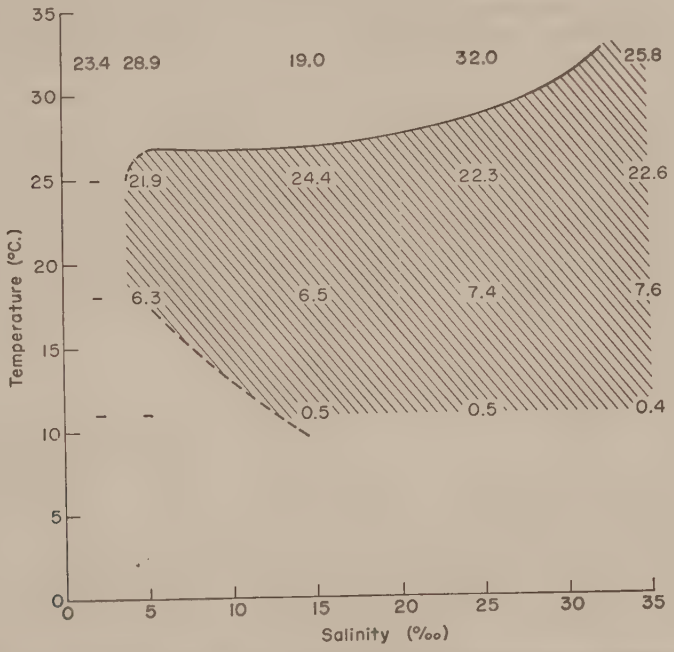

FIGURE 5. Growth and survival of young *P. aztecus* held 28 days at indicated levels of temperature and salinity. Numbers indicate increase in mean length (mm.). Hatched zone indicates 80–100% survival.

The temperature range permitting growth is more limited than the range for survival (Fig. 5). Our laboratory studies have demonstrated that growth can occur over a wide range of salinity at temperatures of 25° C. and above, and suggest that the effect of temperature upon the rate of growth increases rapidly with temperature between 11° and 25° C. (Fig. 6). This effect of temperature has been confirmed in more recent experiments in which we observed growth at a greater number of temperature levels between 15° and 35° C. than tested here.

The greatest growth differential per 7° C. was observed between the 18° and 25° C. levels. This difference may well explain the observation of St. Amant, Corkum and Broom (1963, p. 25) that "metamorphosis of postlarvae into rapidly growing juveniles occurs suddenly after water temperature exceeds 20° C." Above 25° C., increasing temperature has less effect upon growth. The recent experiments

referred to above indicate that growth is maximal at 30° to 32.5° C. This result, coupled with the increased mortality at 32° C., suggests that such a temperature condition, although promoting rapid growth in some individuals, may be above the optimum temperature for long-term growth and survival of *P. aztecus* postlarvae.

The laboratory evidence suggests that normal winter temperatures render the brackish bay systems unfavorable for both survival and growth of brown shrimp postlarvae, whereas almost any salinity will provide a favorable environment at normal summer temperatures. Thus, the pattern of tolerance to salinity and temperature observed in the laboratory may explain the seasonal distribution of *P.*

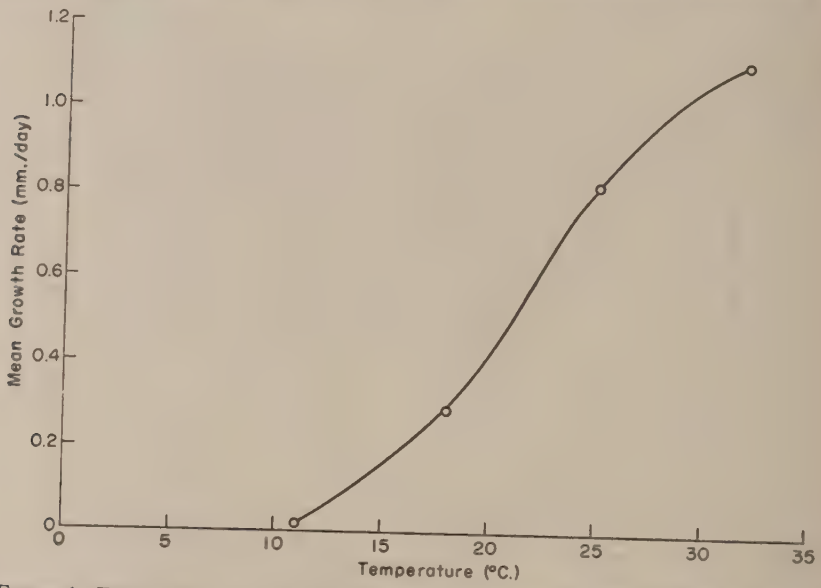

FIGURE 6. Effect of temperature on the laboratory growth rate of young *P. aztecus* (salinity: 25‰; length of experiment: 28 days; initial length of experimental shrimp: 12.1 mm.).

aztecus in much the same manner as described by Broekema (1941) for the migratory European shrimp, *Crangon crangon*. Survival of postlarvae within the estuary may also be affected by decreases in temperature or salinity. In the spring, postlarvae entering bays having relatively low temperatures and salinities above 15‰ may be adversely affected by a sudden salinity drop, such as that caused by heavy spring rains. Conversely, if the temperatures are intermediate (18° C., for example) but salinities low (10‰ or less), a drop in temperature may also decrease survival. Simultaneous decreases in both physical factors—temperature and salinity—would be most detrimental to the population in terms of both survival and growth.

Williams (1960) had previously noted the effects of temperature and salinity on juveniles and subadults of *P. aztecus*. Not only did he find that the 96-hour survival of 42- to 100-mm. specimens declined with decreasing temperature over

the range 28.8° C. to 8.8° C., but he also determined that survival was most markedly reduced at 10‰ (the lowest salinity tested) regardless of the temperature. Animals exposed to 8.8° C. showed a greater tendency to lose the ability to regulate the osmotic concentration of the serum. It is of interest that juveniles were better able to regulate serum concentration than were adults (120 to 150 mm.) exposed to the same conditions. McFarland and Lee (1963) demonstrated that brown shrimp adults were better osmoregulators at higher salinity than at lower, with a greater tendency to isosmoticity when the external medium was below 18‰. The latter authors were unable to study animals in salinities below 5‰ to 6‰ since only one of 12 adults survived 24-hour exposure to this range of salinity, despite an acclimation period of almost one week.

The studies cited above suggest that salinity tolerance may vary not only with temperature, but also with size (age) of the shrimp. In demonstrating good survival of *P. aztecus* postlarvae over a broad range of salinity and temperature, the findings presented here suggest that postlarvae of this species are better osmoregulators than juveniles, which were tested by Williams (1960), or the adults tested by McFarland and Lee (1963). Further studies are planned to determine the effects of both temperature and salinity upon the osmotic behavior in various life-history stages of *P. aztecus* and *P. setiferus*.

Summary

1. The combined effects of salinity and temperature upon growth and survival of postlarvae of the brown shrimp, *Penaeus aztecus*, were studied under controlled conditions.

2. Test salinity ranged from 2‰ to 40‰ and temperature from 7° to 35° C.

3. With relatively short periods of acclimation, postlarval brown shrimp withstood wide fluctuations in both temperature and salinity for 24 hours.

4. The range of tolerance to these factors over periods of 28 days was only slightly less than that observed for 24 hours.

5. Postlarvae survived temperatures as low as 11° C. with almost no growth for one month in salinities of about 15‰ or above.

6. Growth increased with temperature, with significant growth beginning at some temperature above 11° C. but below 18° C. The most marked increase in growth rate occurred in the temperature region between 11° and 25° C.

7. At temperatures below 15° C., young (postlarval) shrimp demonstrated a decreased tolerance to low salinity. This reduced tolerance may influence the natural distribution and survival of postlarvae, which do not ordinarily enter the estuaries in abundance until spring when the temperature has increased to levels at which characteristically low estuarine salinities are no longer harmful.

8. Salinity *per se* had little effect on either survival or growth, except at extreme temperatures.

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Vol. 94, No. 3, July 1965
pp. 277–278

Effects of Injected Biological Stains on Oxygen Uptake by Shrimp[1]

Rates of growth and mortality in populations of fish and shellfish may be estimated by means of mark–recapture experiments. Unfortunately, some tags or marks adversely affect the behavior, physiology, and survival of the animals involved (Clancy, 1963; Barrett and Connor, 1962). Accordingly, their careless use can result in biased estimates of growth and mortality parameters.

Estimates of these parameters for populations of several penaeid shrimps have been obtained from experiments in which biological stains were used as the marking agent (Klima, 1964; Kutkuhn, in press). The effects of such stains on the physiology and growth of shrimp had not, however, been previously investigated. Since the injected dye concentrates in the gills of the animal, the question has arisen as to whether or not it impedes oxygen uptake through physical clogging or by chemical injury to the gill tissue. It is hypothesized that any inhibition of respiratory activity could reduce the shrimp's metabolic rate and thereby retard its growth. The following experiments were designed to measure the influence of biological stains, if any, on oxygen uptake by shrimp.

Prior to experimentation, brown shrimp, *Penaeus aztecus*, ranging in total length from 83 to 110 mm, were conditioned to a recirculating seawater medium for several days. Half the shrimp were then injected with a 0.5% solution of fast green (FCF) stain following the method described by Costello (1964), and half were established as a control group (Tables 1 and 2). The oxygen consumed by whole shrimp, as well as by gill tissue excised from stain-marked and unmarked shrimp, was measured daily for 5 days following the start of the experiment. Final measurements were made on the 11th day. Determinations of oxygen uptake by the whole animal were made using the Winkler technique described by Strickland and Parson (1963, p. 23–28). The oxygen consumed by individual gill filaments was measured in Warburg respirometers.

[1] Contribution No. 204, Bureau of Commercial Fisheries Biological Laboratory, Galveston, Texas.

TABLE 1.—*Oxygen uptake by whole brown shrimp, expressed as ml O_2/g per hr (wet weight)*

Tested group	Number of experimental animals	Average oxygen consumed	Standard deviation
Stained	12	0.29	0.08
Unstained	12	0.31	0.07

Shrimp in both the treated and control groups were exercised for 10 minutes before experimentation to stimulate their respiration. They were then isolated in plastic containers of about 5 liters' capacity. A sample of the medium in each container was then withdrawn to determine its initial oxygen content. Thereafter, each shrimp was allowed to respire in the closed container for 1 hour. The oxygen taken up by individual animals was calculated as the difference in oxygen content of the water at the beginning and end of the experimental period.

Gill tissue was removed from shrimp used in the whole-animal experiments as well as from four other specimens selected at random for each test. Such material, kept separate for each animal, was placed in 15-ml Warburg respirometer flasks containing 3.0 ml of filtered seawater. Carbon dioxide was absorbed with 0.2 ml of a 10% KOH solution. Oxygen uptake was measured for a period of 1 hour, since it was determined that respiration was maintained at a constant rate under these conditions (Figure 1).

Analyses of the experimental results were simplified because the amount of oxygen consumed by whole animals and by the isolated gill tissue did not change significantly from day to day. Nor was there any significant trend in oxygen uptake with time.

The average quantities of oxygen taken up by whole shrimp and excised gill tissue are given in Tables 1 and 2. These statistics indicate no difference in the amount of oxygen consumed by stained and unstained shrimp. We therefore conclude that the presence of

TABLE 2.—*Oxygen uptake by gill tissue excised from brown shrimp, expressed as μl O_2/mg per hr (dry weight)*

Tested group	Number of experimental animals	Average oxygen consumed	Standard deviation
Stained	24	4.67	1.04
Unstained	24	4.70	1.01

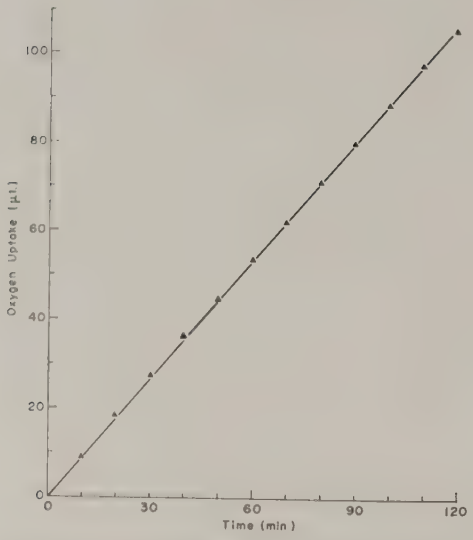

FIGURE 1.—Oxygen uptake of gill tissue from subadult brown shrimp as a function of time.

fast green (FCF) does not grossly effect the metabolic rate of brown shrimp. This finding increases our confidence in the reliability of growth-parameter estimates derived from the results of shrimp mark–recapture experiments in which this dye is used.

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